Measurement of the *t*-quark pair (*tt*) production cross-section using final states with a lepton and a hadronically decaying τ-lepton

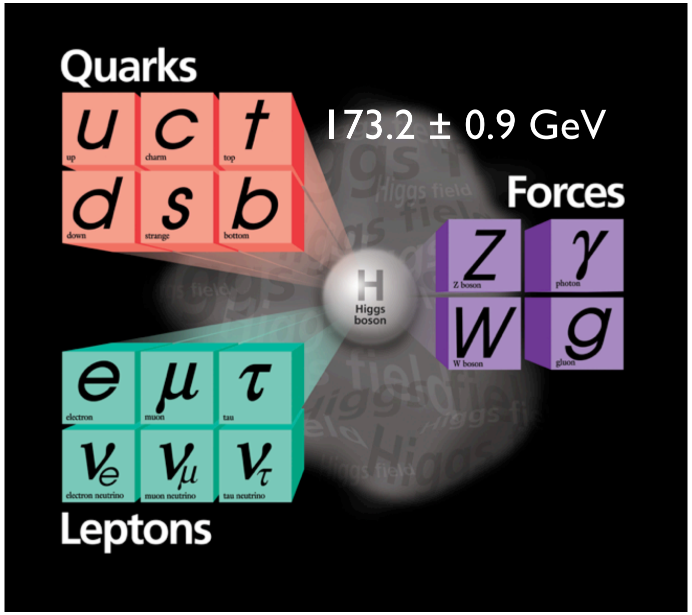
Yuta Takahashi, Nagoya university

25, Sep, 2012

Fermilab Interview

Physics Motivation

- **The Standard Model (SM)**
  - 6 quarks + 6 leptons
  - Interaction mediated by gauge fields
  - Higgs boson at 125 GeV ?



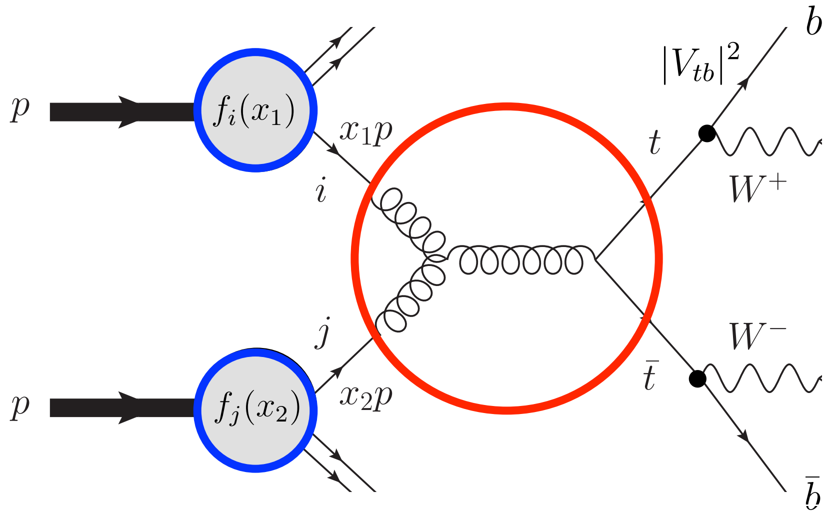
- **The *t*-quark**
  - Heaviest elementary particle so far
  - $Y_t = 1$, best probe to reveal the mass generation mechanism

- **LHC is the *t*-quark factory**
  - Enabling closer look at *t*-quark with unprecedented accuracy

Understanding the *t*-quark pair production cross-section (σ_{tt}) at the LHC is the best starting point to test the SM and look for beyond

σ_{tt} measurement at ATLAS

- Formulation of the σ_{tt} at the proton-proton collider



$$\sigma_{p\bar{p}\to t\bar{t}} = \boxed{\sum_{i=g,q,\bar{q}} \int_0^1 f_i(x_1)\, dx_1 \int_0^1 f_i(x_2)\, dx_2}$$

$$\boxed{\times \hat{\sigma}_{ij\to t\bar{t}}\ (\alpha_s)}$$

$$\boxed{\times\ |V_{tb}|^4}$$

$$= 165^{+11}_{-16}\ \text{pb}$$

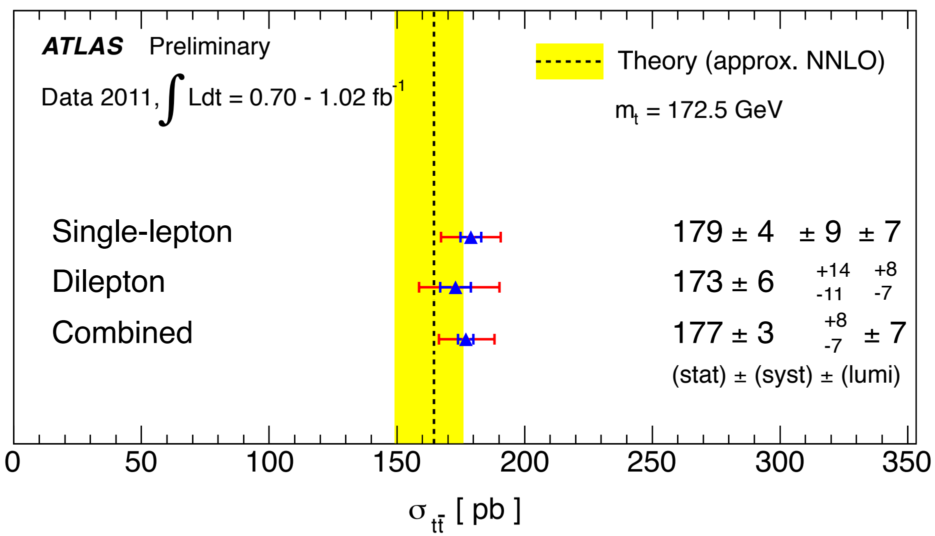
PDF

Strong coupling constant

CKM matrix Vtb

Precise measurement has been performed using clean channel

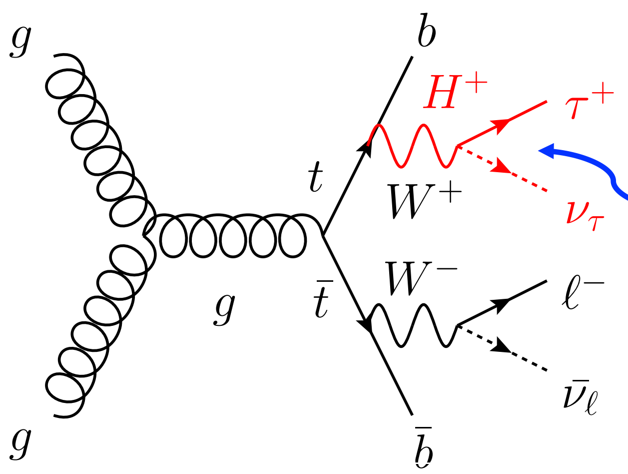
- Dilepton ($tt \rightarrow$ llννbb) and Single-lepton ($tt \rightarrow$ lνjjbb) channel
- δσ(Measured) (6%) < δσ(Theory) (10%)
- Strongly validated the SM



Goal of the analysis

Measurement of the *tt* production cross-section in τ and lepton (an electron or a muon) **final state**

1. Alternative test of the SM, especially in decay process
2. Looking ahead the search for the charged Higgs boson



$$\tan\beta = \frac{v_u}{v_d}$$

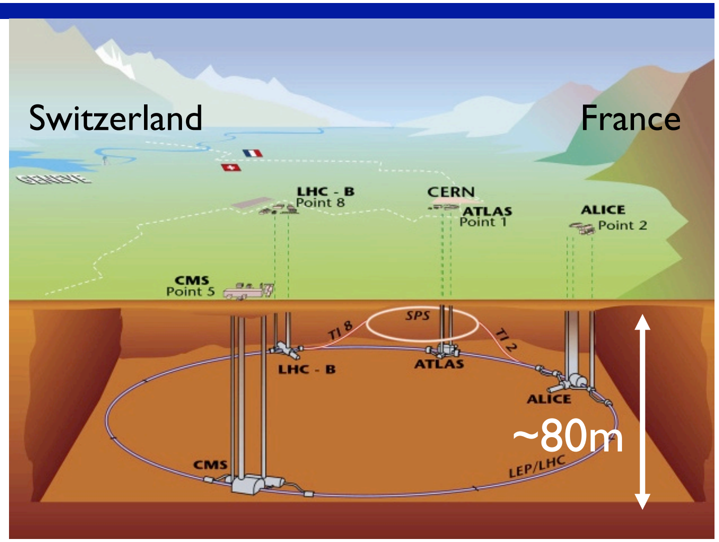
$$\frac{g}{\sqrt{2}M_W}\left\{m_u\left(\frac{1+\gamma_5}{2}\right)\frac{1}{\tan\beta} + m_d\left(\frac{1-\gamma_5}{2}\right)\tan\beta\right\}$$

Dominant
at large tanβ
($H^+ \to \tau^+\nu$)

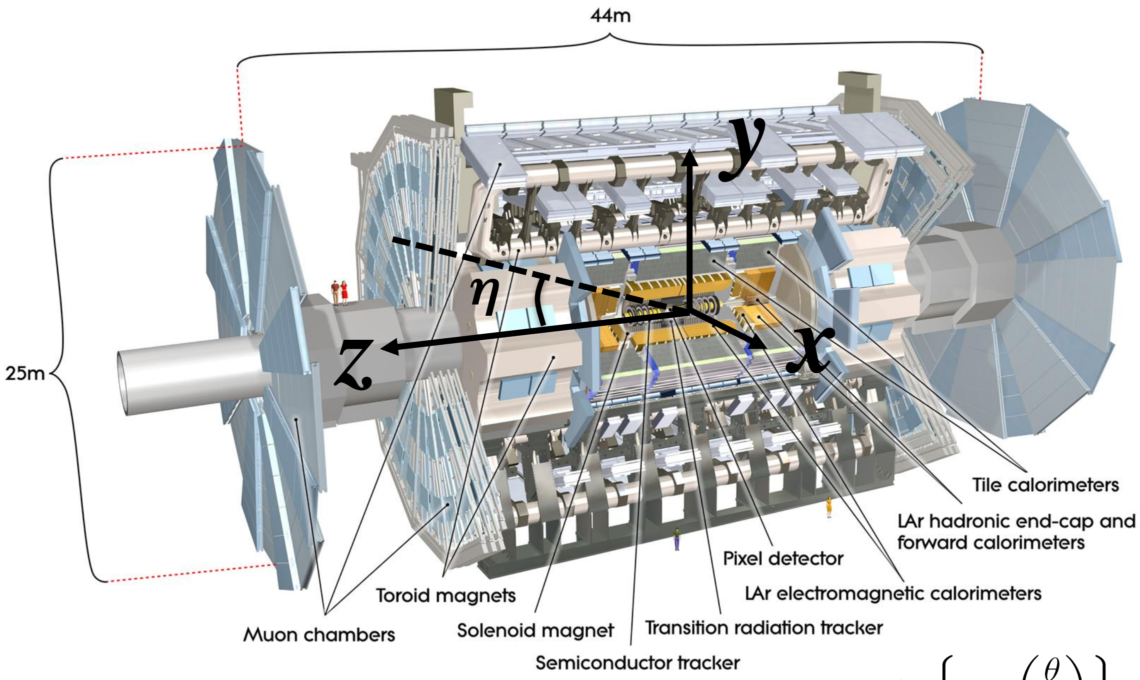
- Challenging due to the difficulties of the τ-identification
- Important milestone to be achieved at the LHC

LHC – ATLAS experiment

- **Large Hadron Collider (LHC)**
  - World highest-energy *pp* collider
  - $\sqrt{s}$ = 7 TeV, $L = 10^{33}$ ($1/cm^2s$) in 2011



- **The ATLAS detector**



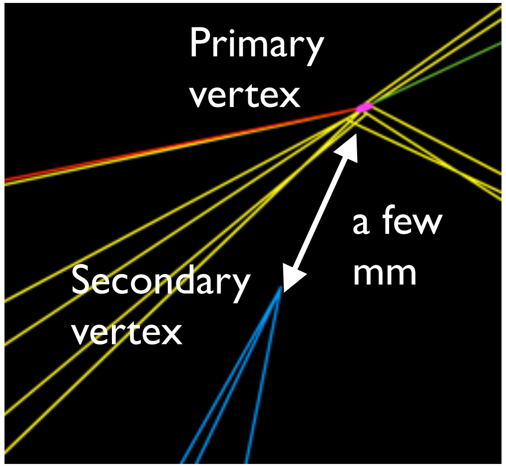
$$\eta = -\ln\left\{\tan\left(\frac{\theta}{2}\right)\right\}$$

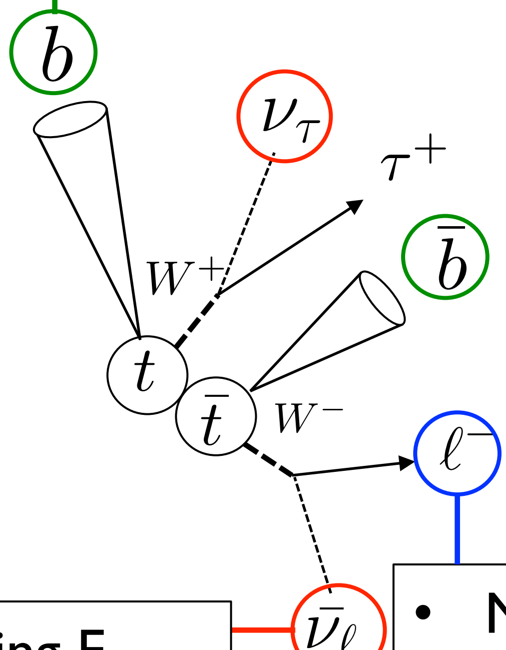
- Inner tracker (|η| < 2.5)
- EM calorimeter (|η| < 3.2)
- Hadron calorimeter (|η| < 4.9)
- Muon detector (|η| < 2.7)

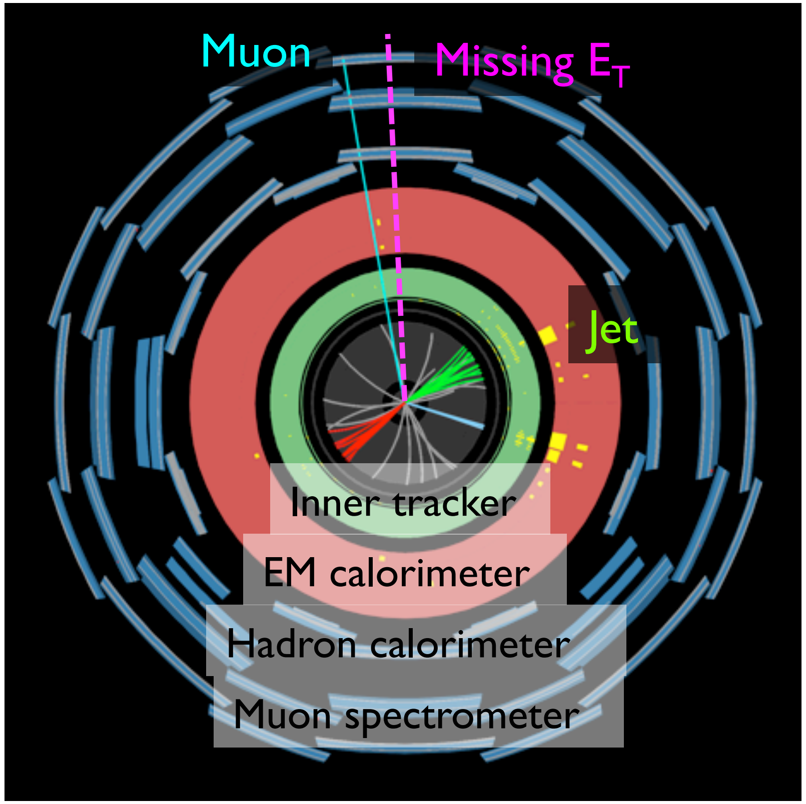
Particle Identification
Momentum &
Energy measurement

Signature of the tt → τ + lepton

- All quarks and gluons are detected as a cluster of hadrons (hadronic jet)
- *b*-jet leaves measurable secondary vertex





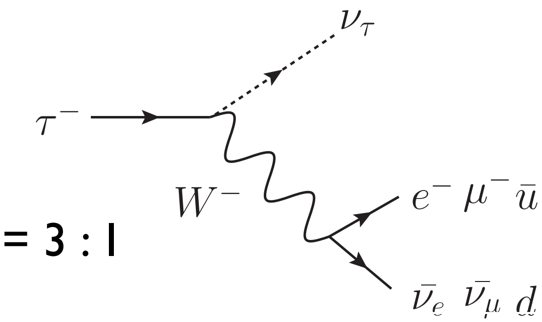


Detected as the missing E_T,
Calculated from p_T imbalance

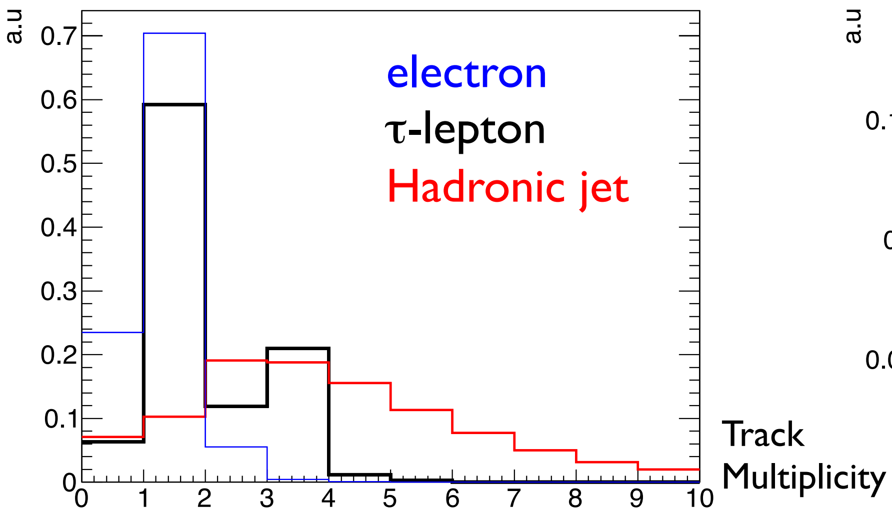
- Muon leaves combined track with inner tracker and Muon detector
- Electron composes EM shower and detected at the EM calorimeter

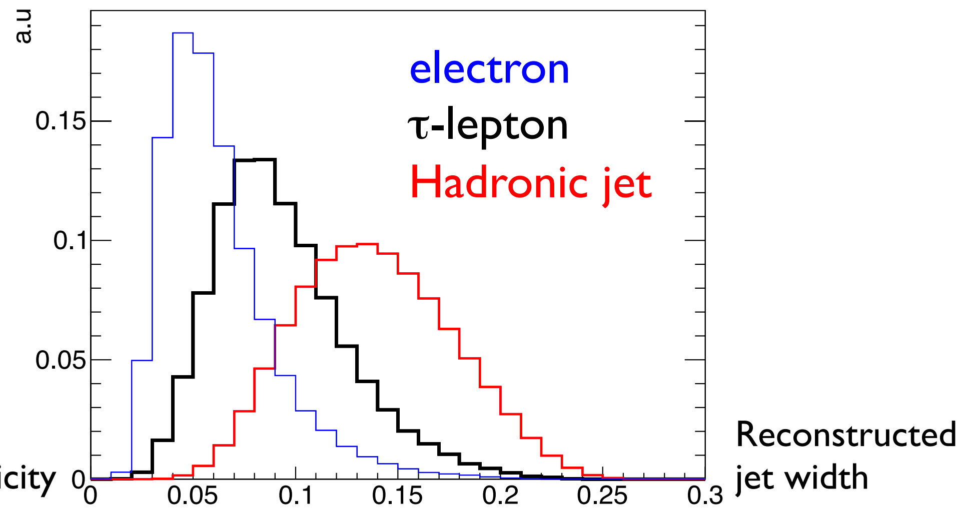
Signature of the τ-lepton

- **Decay products of the τ-lepton**
  - Leptonic decay ($\tau^- \to e^-\bar{\nu}_e \quad \tau^- \to \mu^-\bar{\nu}$) : 35 %
  - Hadronic decay : 65%
    - $\tau^- \to \pi^- + n\pi^0$ (τ_1) : $\tau^- \to \pi^-\pi^+\pi^- + n\pi^0$ (τ_3) = 3 : 1



- **Reconstruction of the τ-lepton**
  - Focus on hadronically decaying τ-lepton only
  - Reconstructed as a jet : Collimated jet compared to the quark/gluon jet





  - A lot of fake τ objects coming from jets (and even from electron)

Cross-section measurement

$$\sigma_{t\bar{t}} = \frac{N_{\text{data}} - N_{\text{background}}}{\varepsilon} \cdot \frac{1}{\mathcal{L}}$$

Number of candidates

Background expectation

Signal acceptance (MC)

Integrated luminosity

Background to be estimated

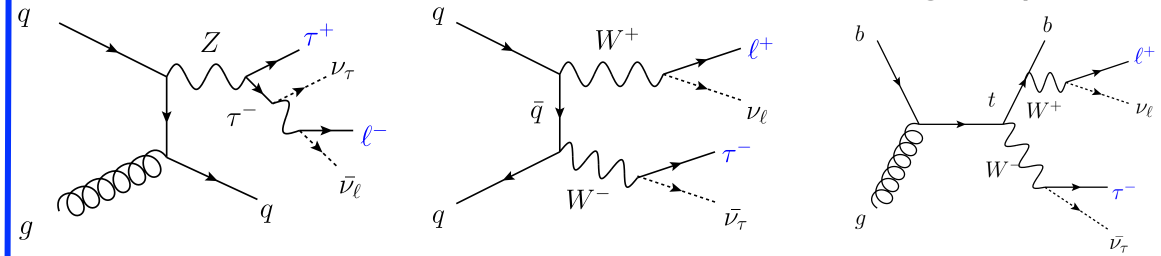
MC simulation

Real lepton
Real τ

Z (→ ττ) + jet

Di-boson

Single-top



Data-driven

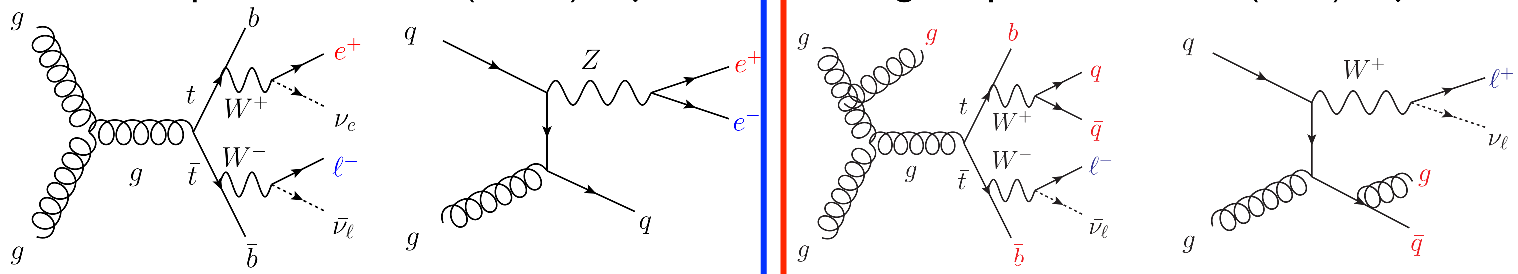
Real lepton
Fake τ

tt di-lepton

Z (→ ee) + jet

tt single-lepton

W (→lν) + jet

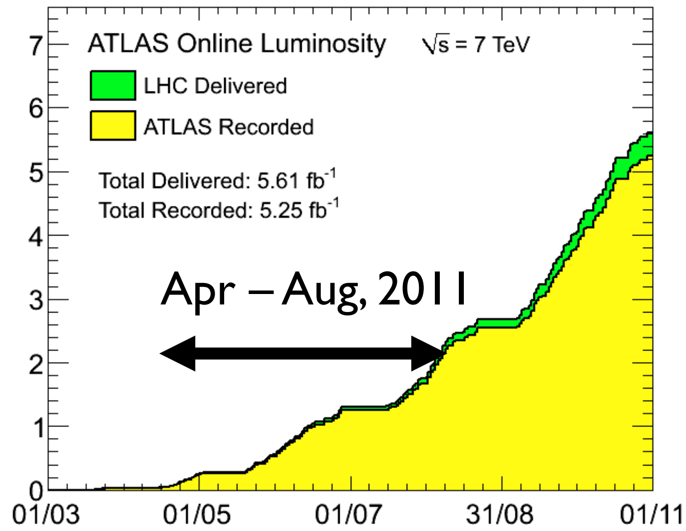


electron faking τ

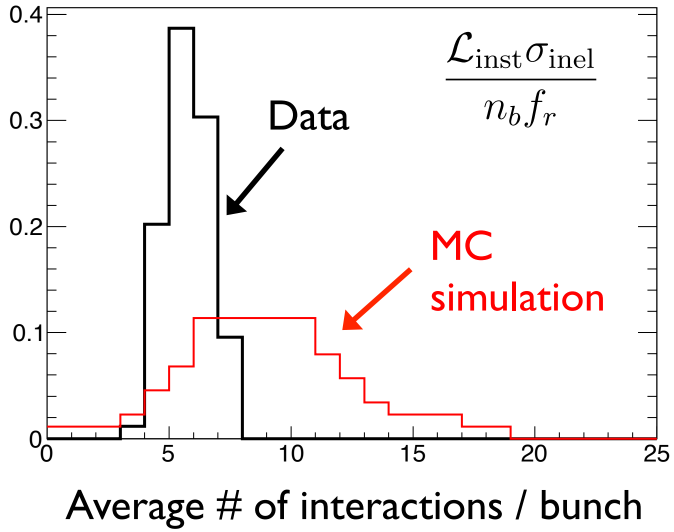
Jet faking τ

Data & MC simulation

- **Data**
  - 2.05 ± 0.08 fb^{-1}
  - Collected by single-lepton triggers
    - Muon (p_T > 18 GeV)
    - Electron (p_T > 20 – 22 GeV)

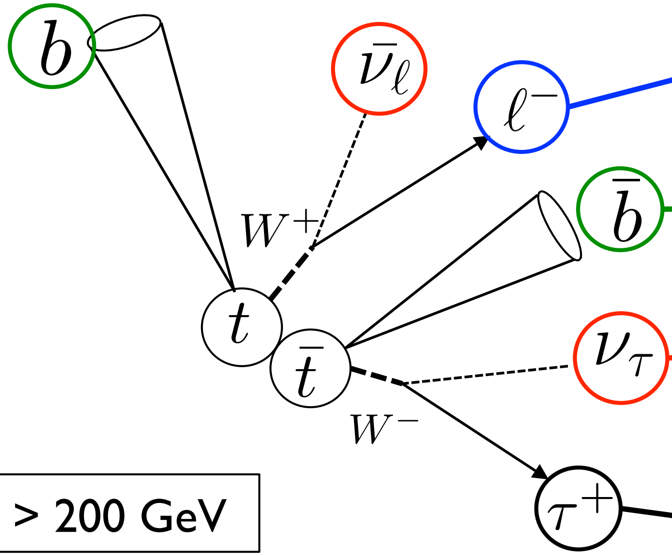


- **Monte Carlo (MC) simulation**
  - *tt*, Z+jet, W+jet, Diboson, Single-top
  - Rescaled to 2.05 fb^{-1}
  - Reweighted to reproduce average number of interactions per bunch crossing to meet actual pileup environment



Event Selection

- Based on the MC simulation to maximize the signal significance



1 Electron (p_T > 25 GeV) or
1 Muon (p_T > 20 GeV)

≥ 2 jets (p_T > 25 GeV)
with at least 1 *b*-tagged jet

E_T^{miss} > 30 GeV

Loose selection

ΣE_T > 200 GeV

≥ 1 τ_{had} candidate
- p_T > 20 GeV
- N_{track} = 1(τ_1) or 2, 3 (τ_3)
- electron veto (multi-variable)

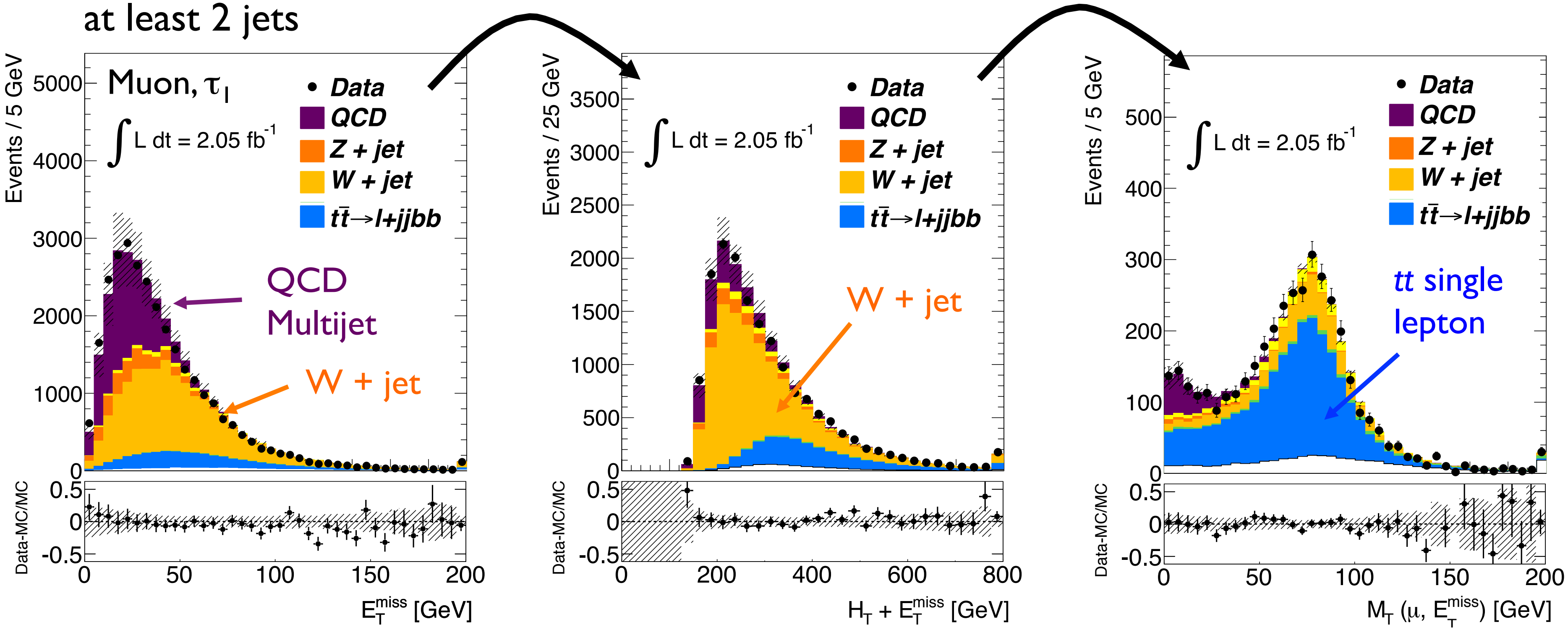
	Muon		Electron	
	τ_1	τ_3	τ_1	τ_3
N_{data} (expected # of signals)	3683 (392)	8693 (120)	3269 (346)	8246 (105)
Signal acceptance (ε)	1.1×10^{-3}	3.5×10^{-4}	1.0×10^{-3}	3.0×10^{-4}

Control plots

1 lepton + 1 τ_{had}
at least 2 jets

E_T^{miss} > 30 GeV

ΣE_T > 200 GeV, ≥ 1 *b*-jet



- Dominant background process : *tt* single-lepton
- ≥ **98%** of the background comes jets faking τ
- 1.5% from irreducible background
- 0.5% from electron faking τ

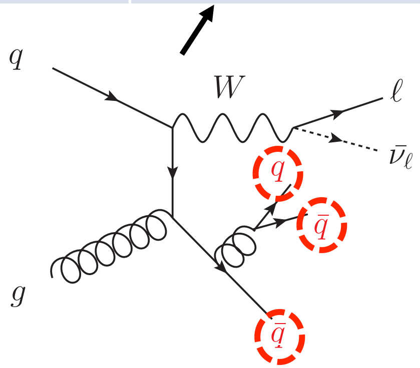
$$M_T(\ell, E_T^{\text{miss}})$$
$$\cong \sqrt{2p_T^{\ell} E_T^{\text{miss}}(1 - \cos \Delta\phi(\ell, E_T^{\text{miss}}))}$$

Overview of the background estimation

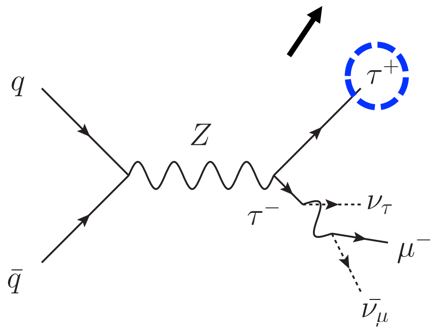
1. **Development of the discriminant variable**
2. **Template fit using discriminant variable**
   - Signal template (MC) + Background template (Data)

	Signal region	0 *b*-jet sample
1 lepton + ≥1 τ cand.	Common	
N_{jet}	≥ 2	
E_T^{miss}	> 30 GeV	
ΣE_T	> 200 GeV	
# of *b*-jet	≥ **1**	**= 0**

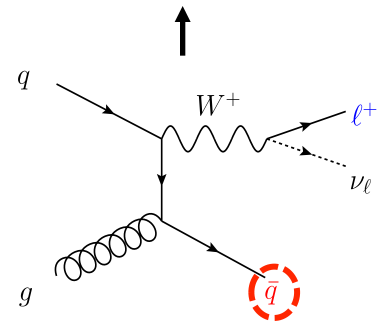
	$Z \rightarrow \tau_\mu \tau_{had}$ sample	W + fake τ sample
1 lepton + ≥1 τ cand.	Common	
N_{jet}	**= 0**	
M_T (ℓ, E_T^{miss})	**< 20 GeV**	**40 – 100 GeV**



Used to construct background template



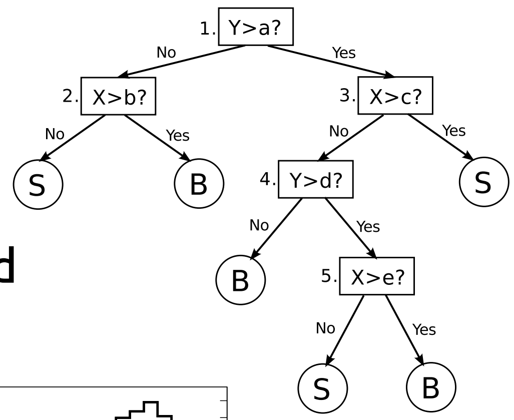
Used to validate signal template

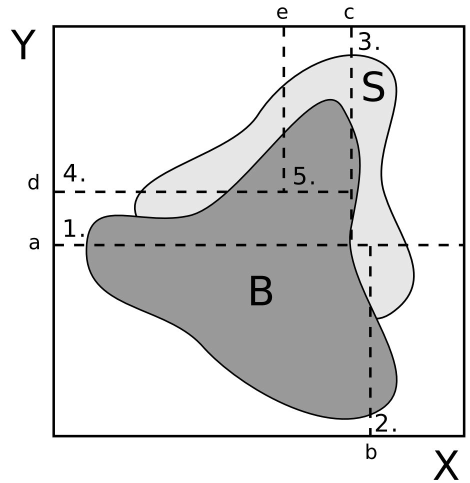


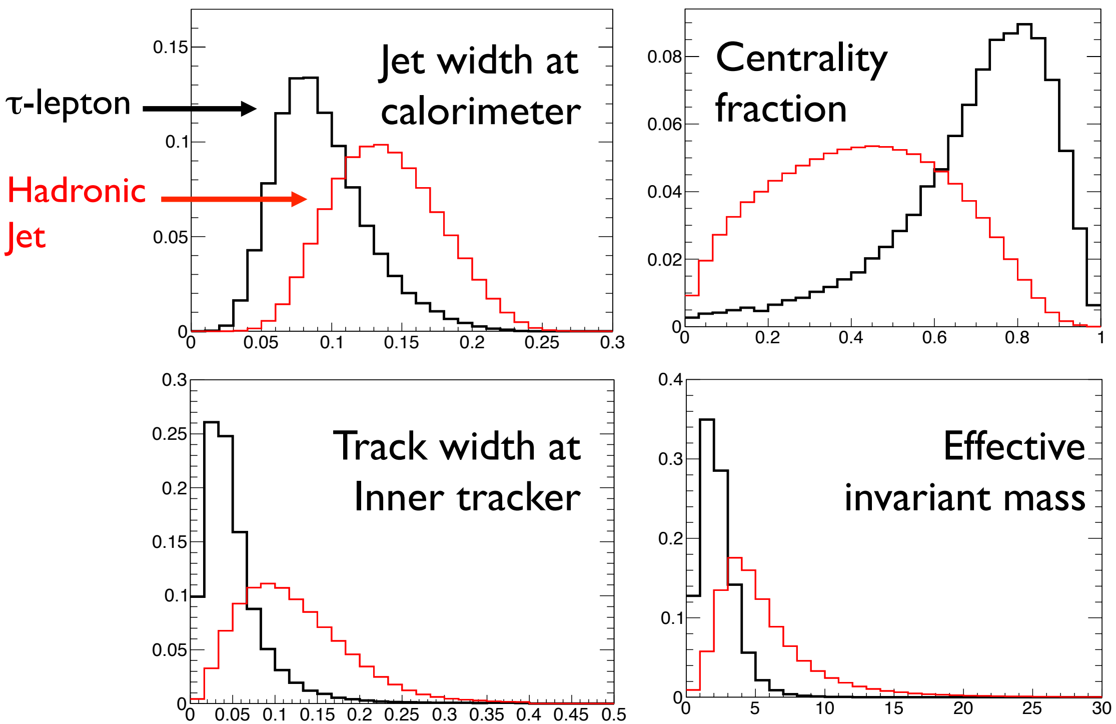
Used to validate background template

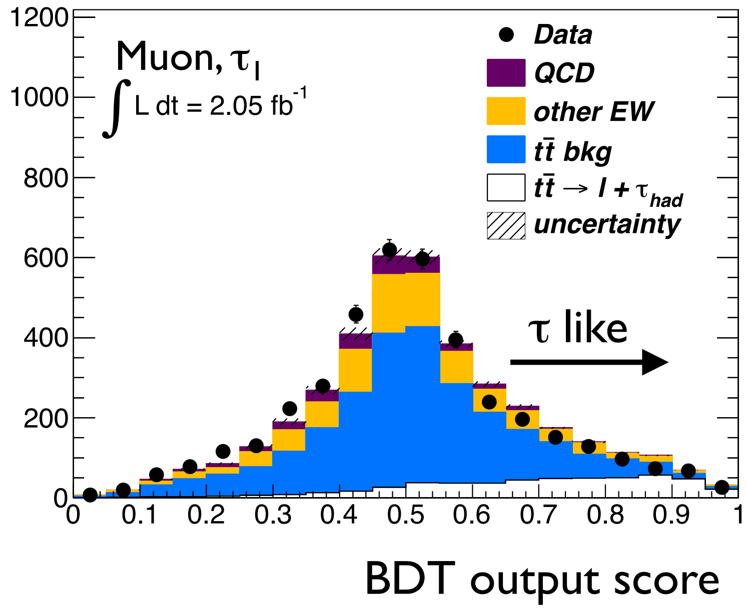
Development of the discriminant variable

- Boosted Decision Tree
  - Recursive cuts on a set of identification variables
  - Trained with 8 (11) jet-related variables for τ_1 (τ_3)



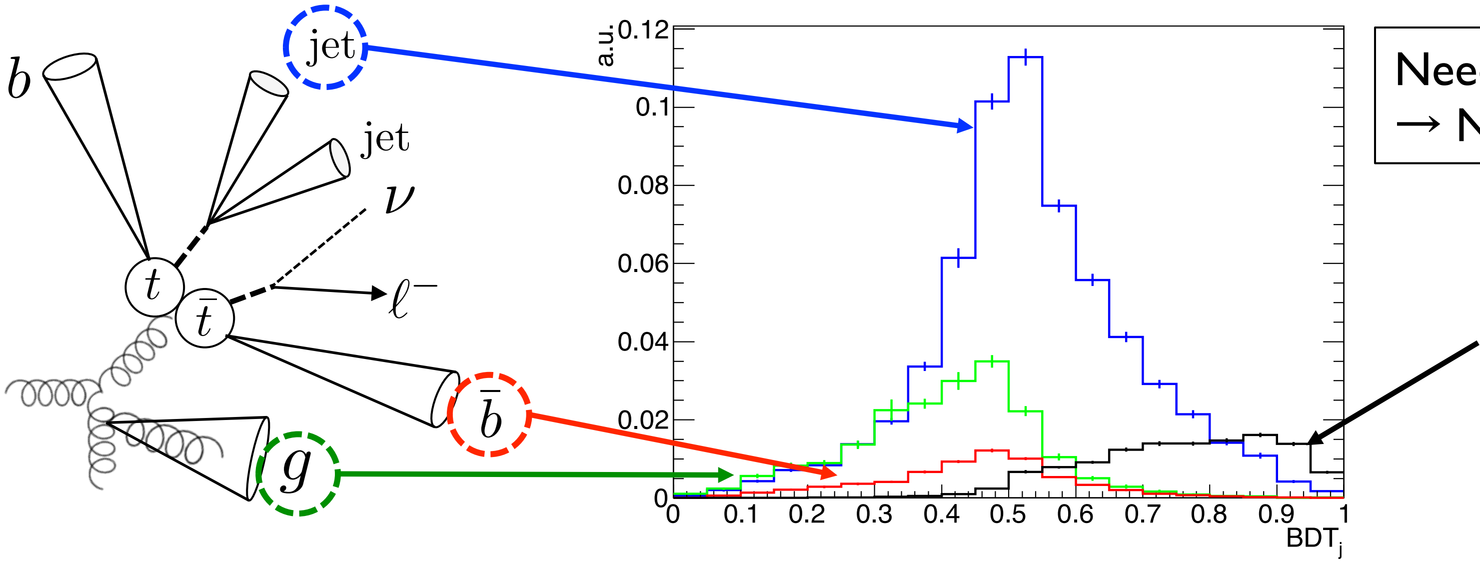






Template fit using BDT output score

- BDT distribution for the fake τ candidate has a different shape according to the jet type : gluon, light-flavor jet (*u,d,c,s*), *b*-jet



Need 4 template ?
→ Not manageable

- Make use of charge correlation between τ and lepton (OS, SS)

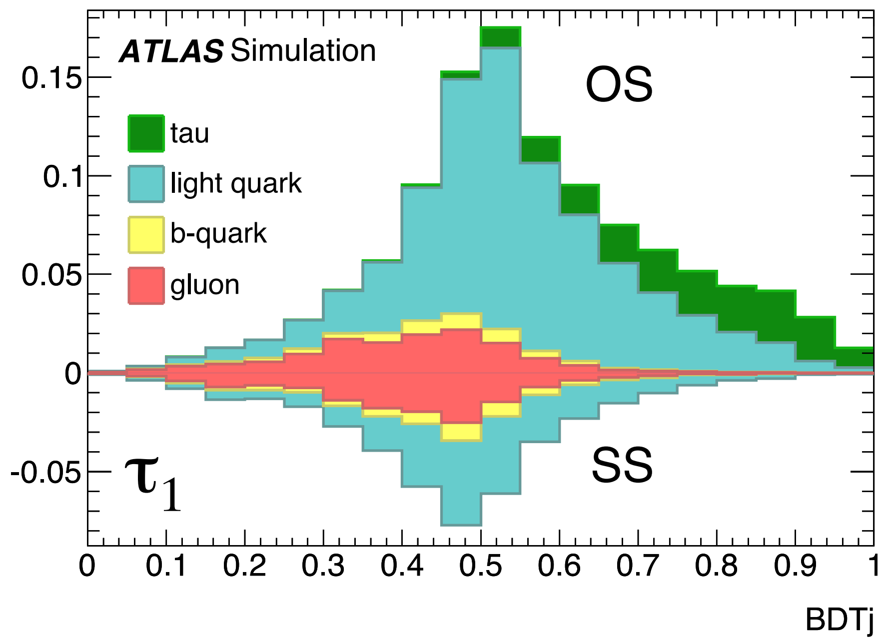
OS = Real τ + b + gluon + light-flavor quark (OS)

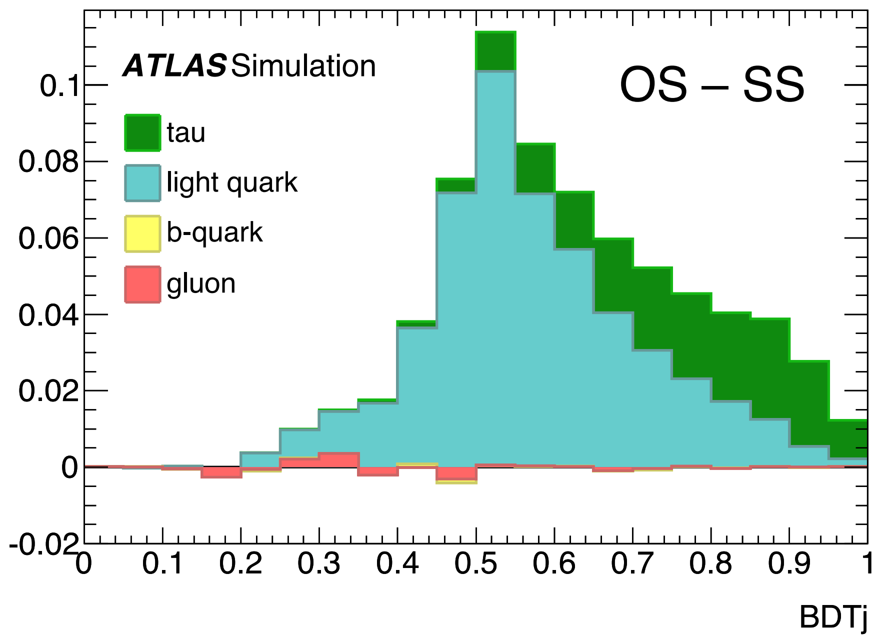
SS = b + gluon + light-flavor quark (SS)

OS – SS = Real τ + light-flavor quark (OS – SS) ⟵ No signal lost

- We can fit OS – SS distribution with only 2 templates

Validation test of the OS – SS technique



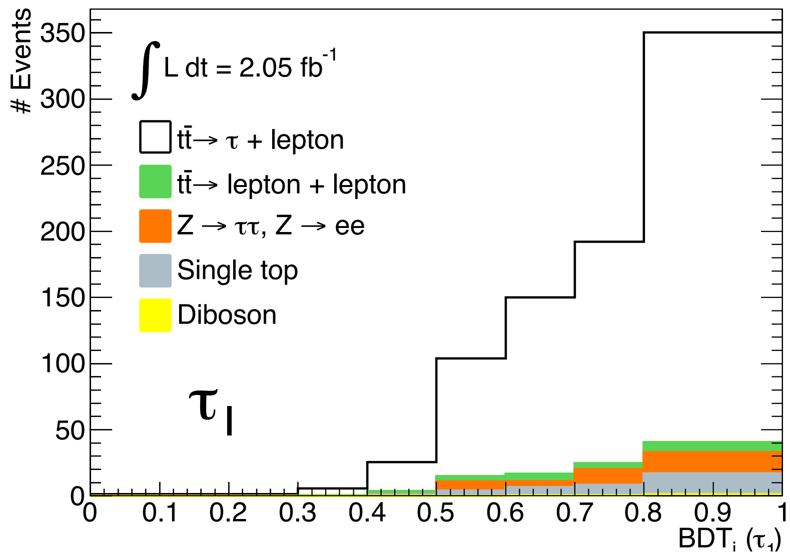


- Gluon, *b*-jet fakes are cancelled out without loosing signals
- Signal events are enhanced and only two components left

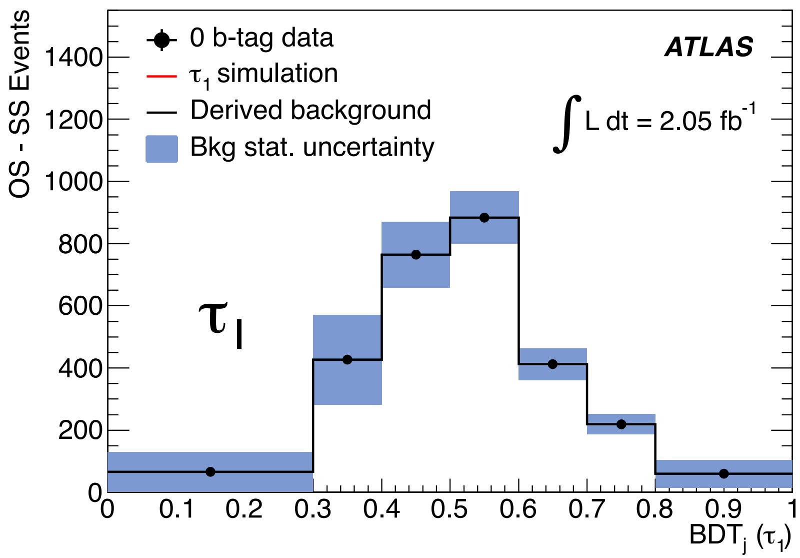
Perform the template fit to the OS – SS BDT output score by using signal and the light-flavor background template

Construction of the template

- **Signal template**
  - Use MC after truth-matching to a real τ-lepton
  - Fake τ from electron is added (subtracted after the fit)

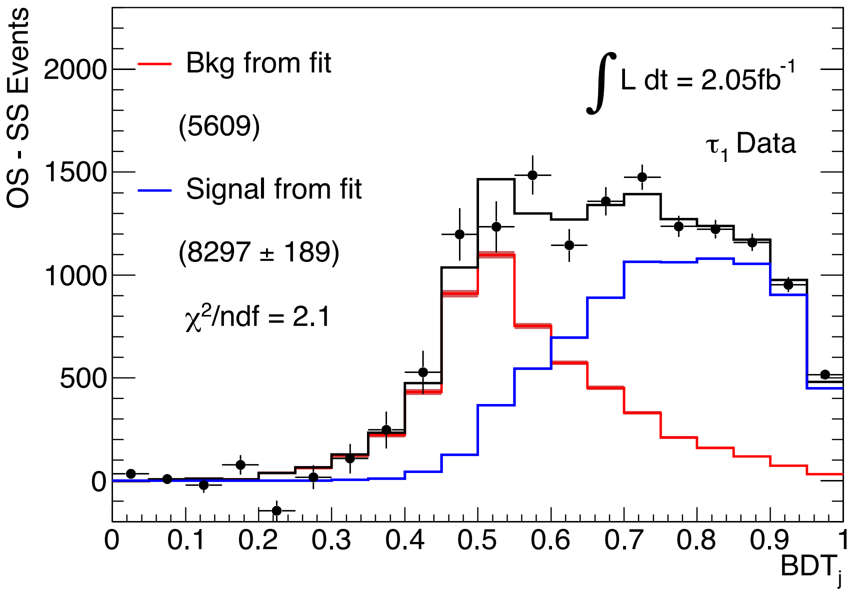


- **Background template**
  - Use 0 *b*-jet sample
  - OS – SS to be light-flavor origin
  - Subtract real τ component (e.g, $Z \rightarrow \tau\tau$) using MC
  - Shape is corrected to reflect kinematic dependence on BDT



Validation of the signal template

- Check the validity to use MC simulation as a signal template
  - Test the template fit method using $Z \rightarrow \tau_\mu \tau_{had}$ sample
  - Signal template (MC) + Background template (W + fake τ sample in data)



	τ_1	τ_3
# extracted signal (± stat.)	8297 ± 189	2871 ± 129
MC expectation (± syst.)	8710 ± 436	2917 ± 204

- Jet energy scale (3% in τ_1)
- Z + jet cross section (4% in τ_1)

Decent agreement is seen within uncertainty

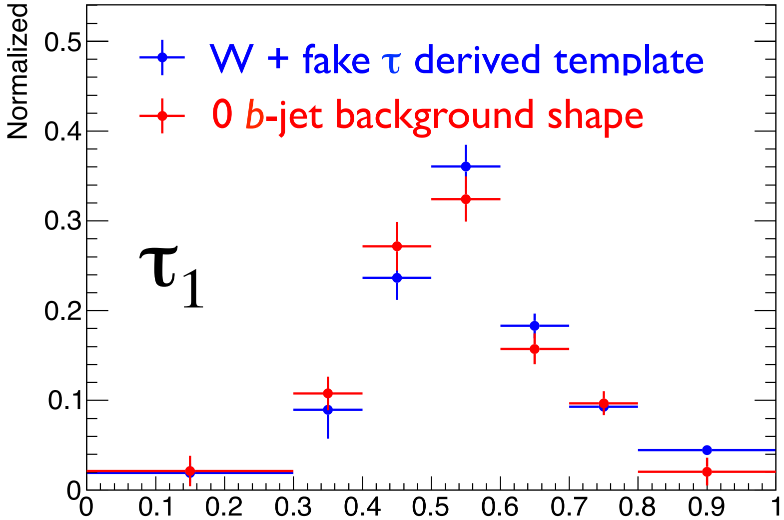
- MC simulation can be used as a signal template
- Systematic uncertainty of 5% (τ_1) and 7% (τ_3) is assigned as the τ identification uncertainty on the signal acceptance

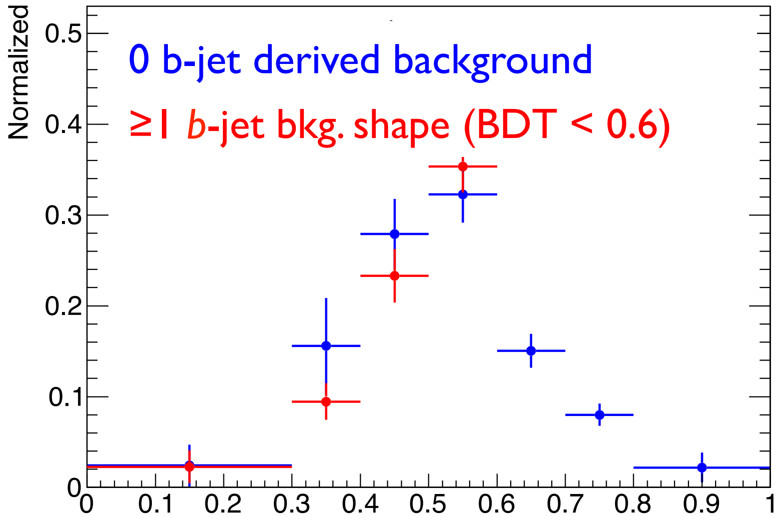
Validation of the background template

1. Compare the background template derived from W + fake τ sample to that of in 0 *b*-jet region

$$(W + \text{ fake } \tau)_{\text{Data}} \times \frac{(0\ b\text{-jet})_{\text{MC}}}{(W + \text{ fake } \tau)_{\text{MC}}} \Longleftrightarrow (0\ b\text{-jet})_{\text{Data}}$$

2. Compare the background template derived from 0 b-jet sample to that of in signal region (BDT < 0.6)





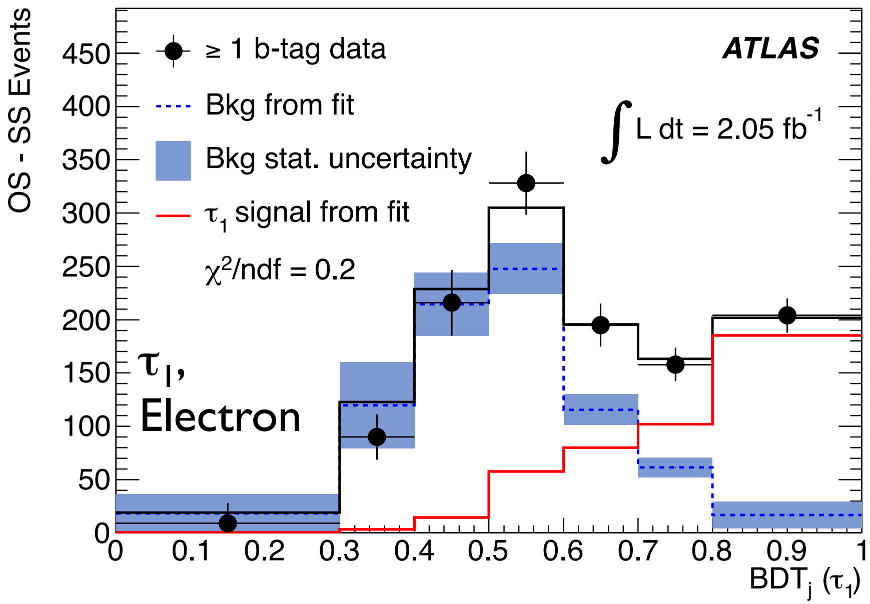
- Construction method of the background template seems to be valid
- No additional uncertainty is added except for the statistical uncertainty

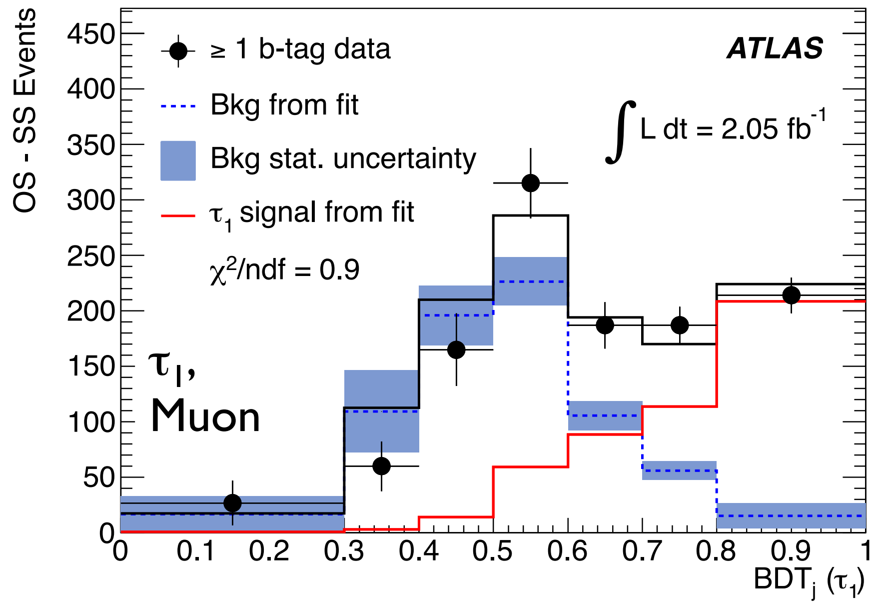
Systematic uncertainty

- Source of systematic uncertainty
  - Estimation of the signal acceptance
  - Signal template
  - Subtraction of the τ contributions in 0 *b*-jet region
- Template fit is performed one by one for each $\pm 1\sigma$ samples

Source	Effect	Electron	Muon
Electron	Identification and Trigger efficiency p_T resolution	2.9 %	
Muon			1.5 %
Jet	Jet energy scale / resolution Jet identification efficiency	3.0 %	2.4 %
Tau	Tau identification efficiency Tau energy resolution	3.0 %	3.2 %
b-jet	*b*-tagging efficiency	8.9 %	9.0 %
Simulation	PDF, MC generator, ISR/FSR, parton shower	4.0 %	4.1 %
Total		**11.0%**	**10.8%**

Template fit in the signal region



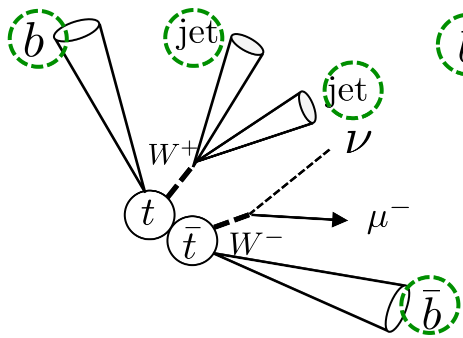


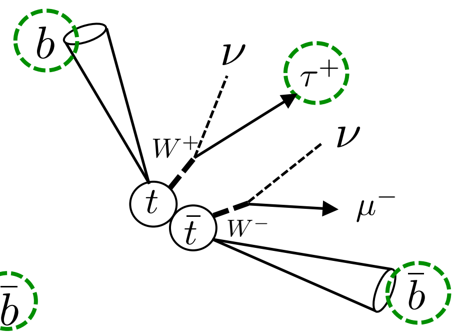
	Extracted # of signals	# of expected (MC)	σ_{tt} (central ± stat. ± syst. ± lumi.)
$\mu + \tau_1$	445 ± 43	388	189 ± 17 ± 20 ± 7 pb
$e + \tau_1$	391 ± 46	338	177 ± 43 ± 21 ± 6 pb
$\mu + \tau_3$	125 ± 33	116	190 ± 20 ± 20 ± 7 pb
$e + \tau_3$	105 ± 30	101	171 ± 47 ± 21 ± 6 pb

- The result shows a decent agreement with expectation in ~1σ

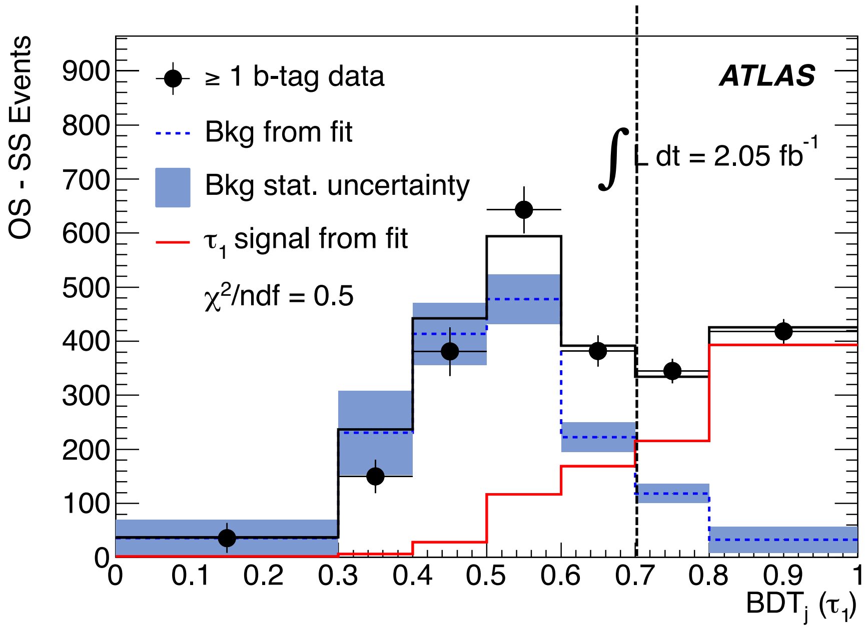
Jet multiplicity distribution

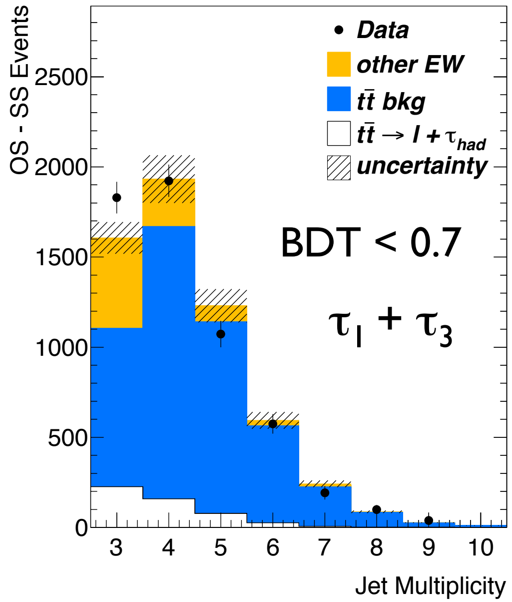
- Jet multiplicity distribution
  - τ candidate is counted as a jet

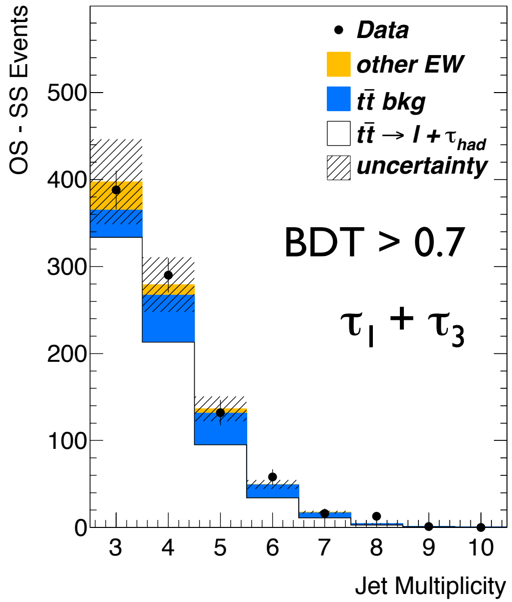




BDT = 0.7



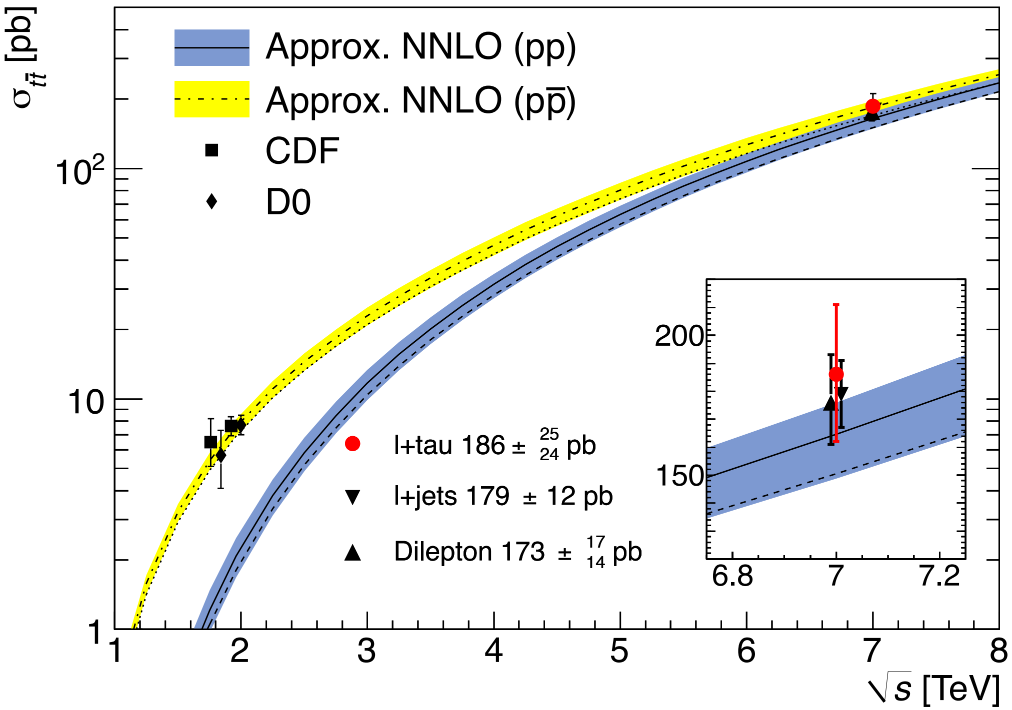


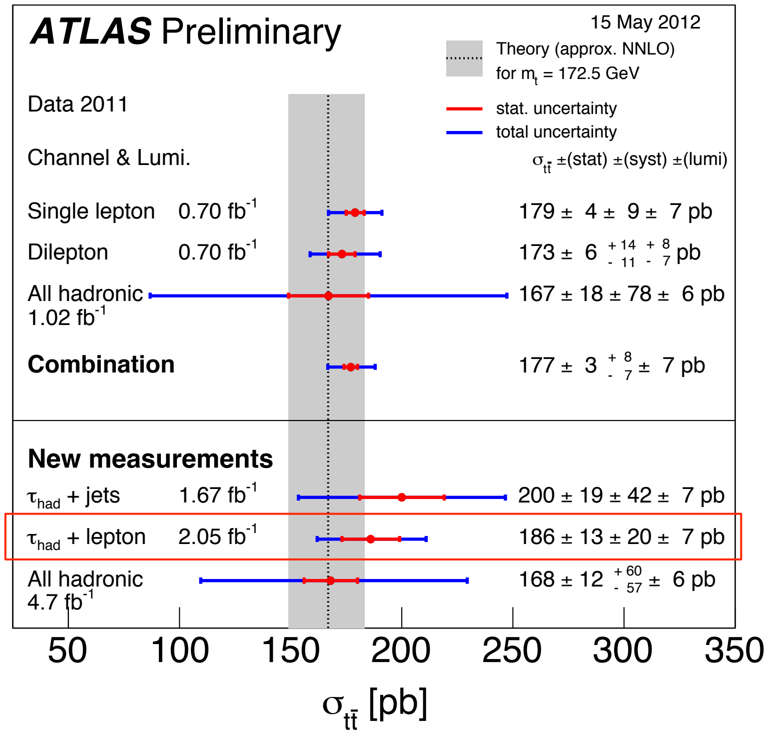


- We actually observe the signal events from the data

Combined cross-section

- Combine all the cross-section measurement
  - σ_{tt} = 186 ± 13 (stat) ± 20 (sys) ± 7 (lumi) pb (MC : 165^{+11}_{-16} pb)
  - $d\sigma/\sigma$ = 13%, most precise measurement in τ + lepton channel, verified the Standard Model including its decay process

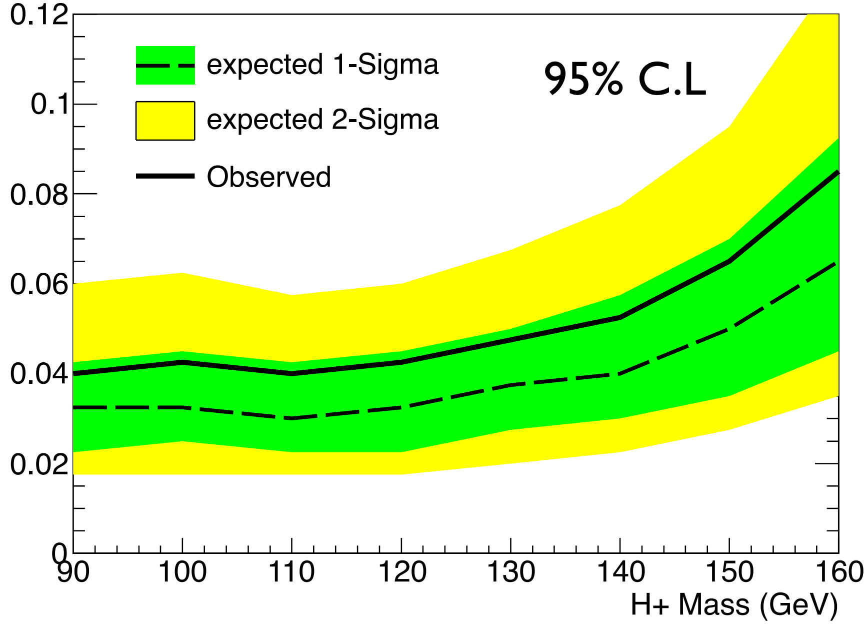




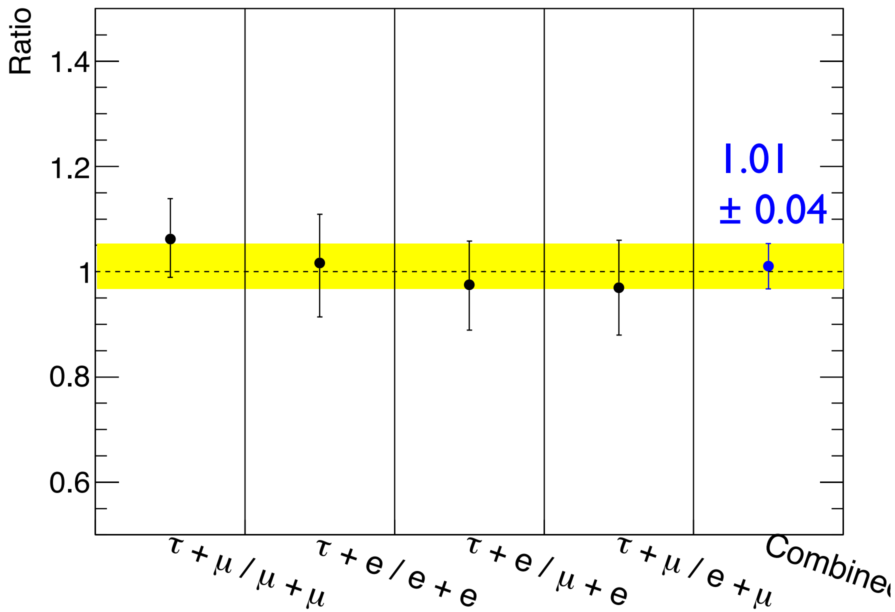
Interpretation to the charged Higgs

- Set the upper limit on $B(t \to H^{\pm}b)$
- Ratio of the observed cross-section between di-lepton and the τ + lepton channel after cancelling out common systematics

$B(t \to H^{\pm}b)$, assuming $B(H^{\pm} \to \tau\nu) = 1$



$\sigma_{tt}(tt \to \tau\text{+lepton}) / \sigma_{tt}(tt \to \text{dilepton})$



- The method developed in this analysis is being used for the new physics search, where $tt \to \tau + X$ is the dominant background

Conclusion

- Establish the method to extract *tt* events including a hadronically decaying τ-lepton from 20 MHz *pp* collisions
  1. Application of the multi-variable & template fit
     → Keep high signal acceptance
  2. OS – SS subtraction
     → Model the background in a data-driven way (reduce systematics)

$\sigma_{tt} = 186 \pm 13\ \text{(stat)} \pm 20\ \text{(syst)} \pm 7\ \text{(lumi)}\ \text{pb}$

✓ The most precise measurement in τ + lepton final state (~13%)
✓ Good agreement with theoretical prediction (165^{+11}_{-16} pb), demonstrating the validity of the SM
✓ Set the upper limit on the branching ratio $B(t \to H^{\pm}b) < 4 – 8\%$
✓ The developed method is being used for the new physics search

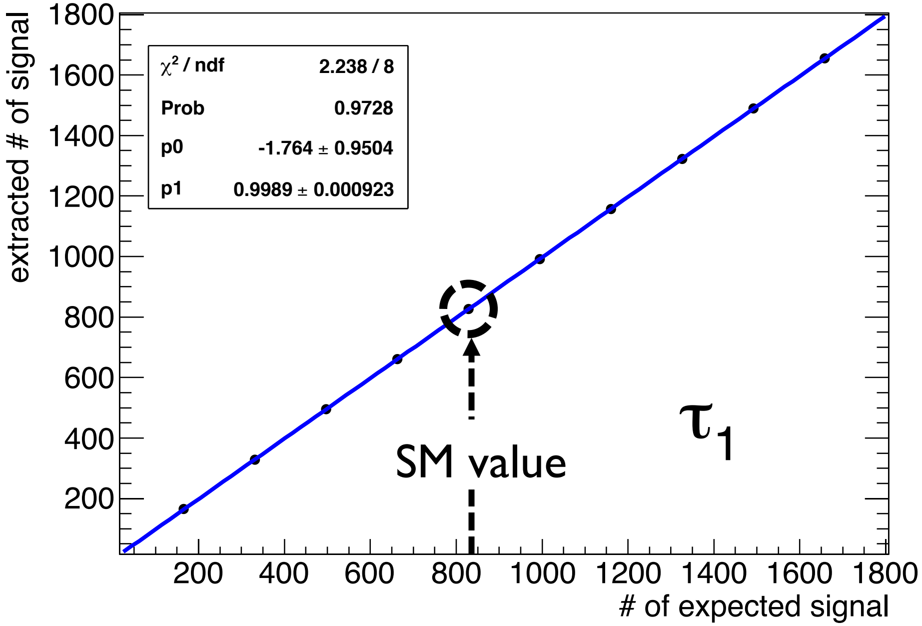
Thank you for your attention

Accepted by PLB on 8, September (arXiv:1205.2067)

Backup slides

Linearity of the fit method

- Perform 5,000 pseudo experiments
  - Fluctuating all the possible distributions by poisson
  - The amount of signals are varied from 0 to twice the SM to check the linearity and the bias of the result

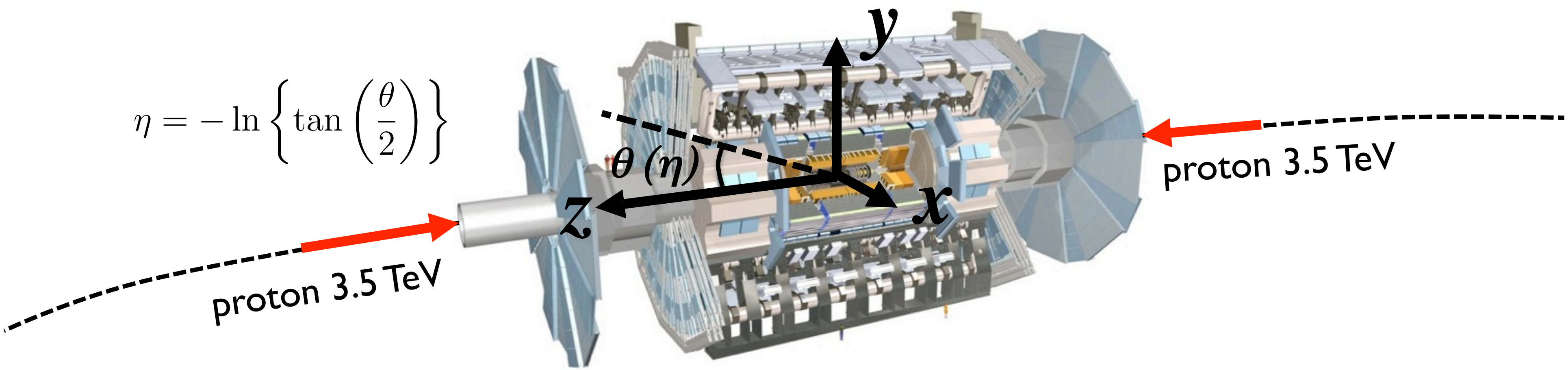


Slope : 1.0
Intercept : -1.7 ± 1.0

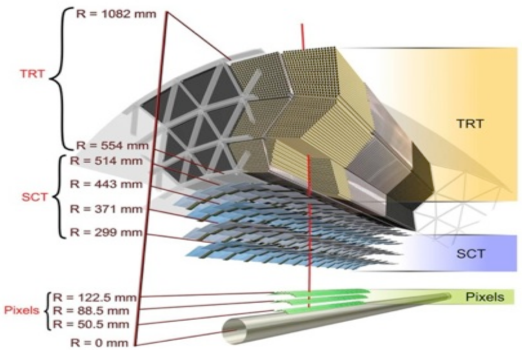
Confirm the good linearity and almost no bias of the result

ATLAS detector

$$\eta = -\ln\left\{\tan\left(\frac{\theta}{2}\right)\right\}$$

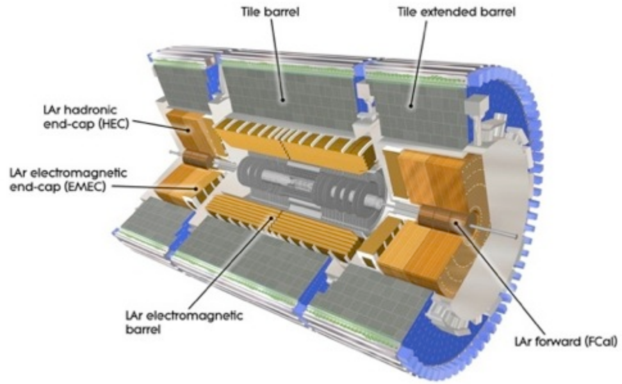


Inner Tracker (|η| < 2.5)



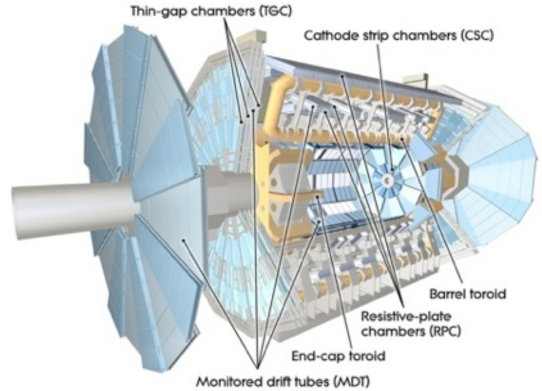
- Pixel (50 x 400 μm^2)
- Semi Conductor Tracker (80 μm)
- Transition Radiation Tracker

Calorimeter



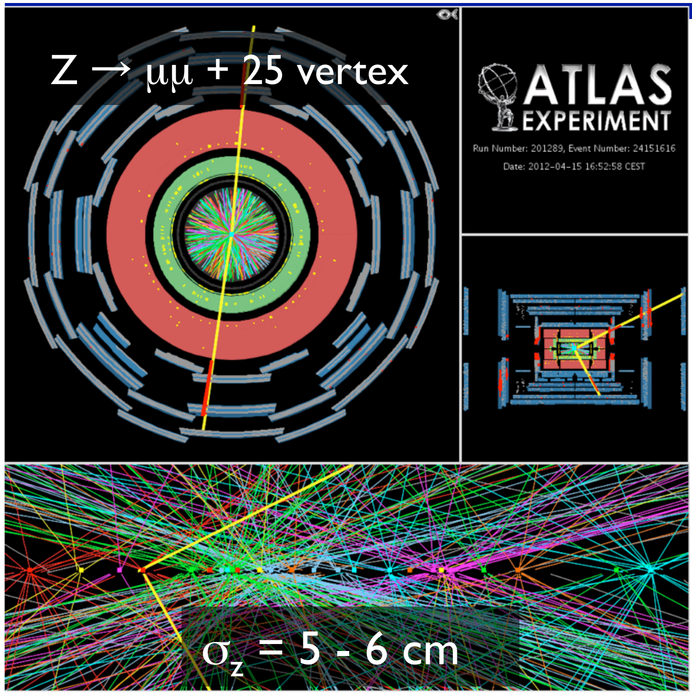
- EM calorimeter (22X_0)
  —|η| < 3.2
- Hadron calorimeter (> 10λ)
  —|η| < 4.9

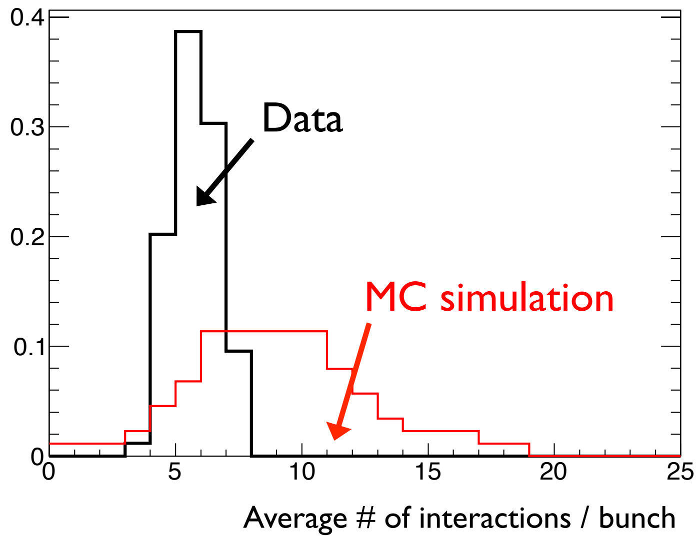
Muon detector (|η| < 2.7)



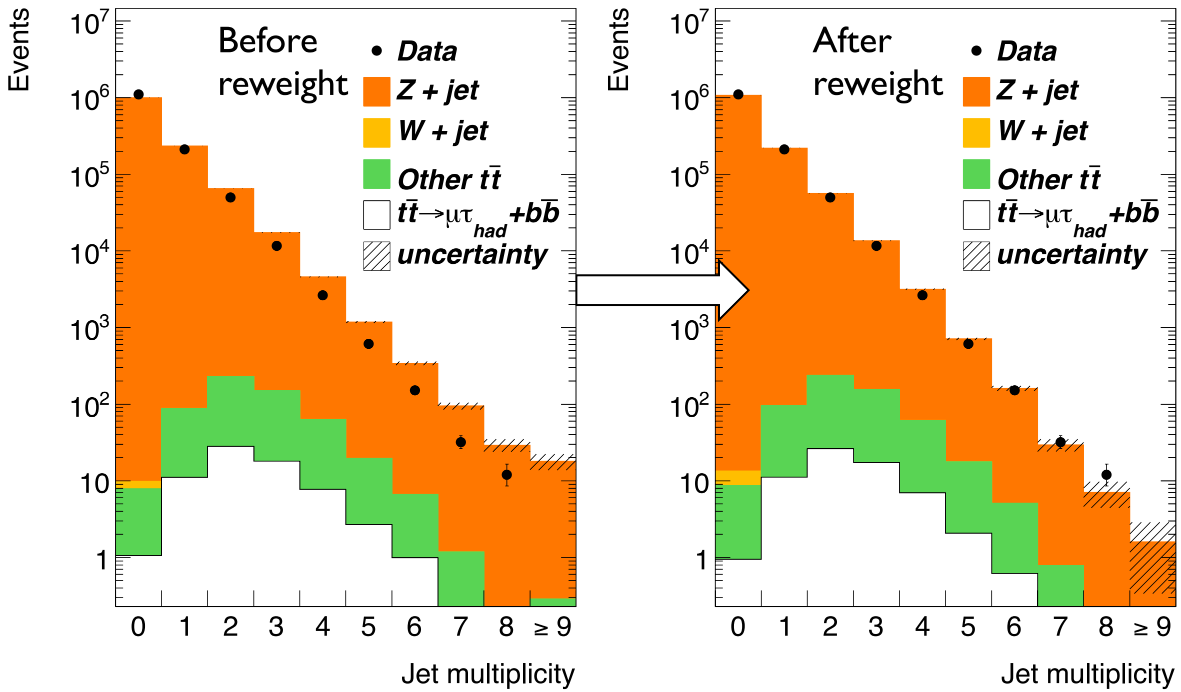
- Precision Tracker
  — Drift Tube detector
- Trigger detector
  — Multi-wire gas chamber

MC tuning to reflect pileup events





- Additional *pp* collisions / bunch crossing
  - MC is reweighted to reproduce average # of interactions per bunch crossing
  - Sanity check using Z → μμ control region for the jet multiplicity distribution



Breakdown of the systematics

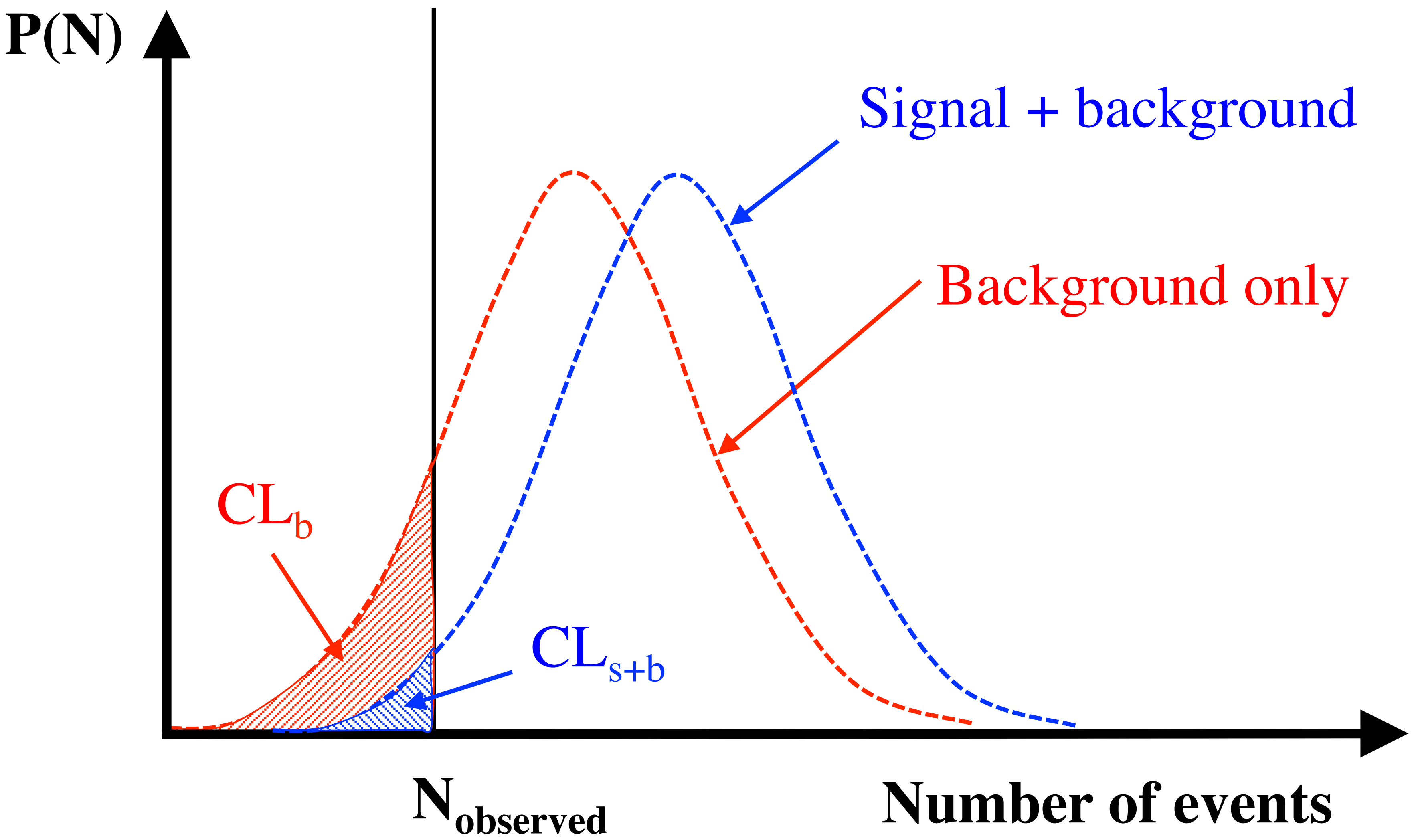
	$\tau+\mu$ $\mathrm{d}\mathcal{A}/\mathcal{A}$ (%)	$\tau+e$ $\mathrm{d}\mathcal{A}/\mathcal{A}$ (%)	$\tau+\mu$ $\mathrm{d}\sigma/\sigma$ (%)	$\tau+e$ $\mathrm{d}\sigma/\sigma$ (%)
muon p_T smearing	0.0 / +0.1	$\pm$0.0	$\pm$0.3	0.0 / +0.1
muon trigger SF	$\pm$1.6	$\pm$0.0	$-$1.1 / +1.5	$\pm$0.1
muon identification SF	$\pm$0.0	$\pm$0.0	$-$0.1 / 0.0	$\pm$0.0
electron p_T smearing	$\pm$0.0	0.0 / +0.2	$\pm$0.2	$-$0.2 / 0.0
electron energy scale	$\pm$0.0	$\pm$0.5	$-$0.3 / +0.1	$-$0.2 / +0.4
electron trigger SF	$\pm$0.0	$\pm$0.8	$-$0.1 / +0.2	$-$0.7 / +1.0
electron identification SF	$\pm$0.0	$\pm$2.9	$-$0.5 / +0.6	$-$2.8 / +2.7
jet energy scale	$-$2.8 / +2.3	$-$3.4 / +3.0	$-$2.0 / +2.2	$-$1.9 / +2.8
jet energy resolution	$\pm$0.5	$\pm$0.4	$\pm$1.0	$\pm$1.2
jet identification efficiency	$\pm$0.0	$\pm$0.0	$\pm$0.2	$\pm$0.0
b-tag SF	$-$5.7 / +5.3	$-$5.3 / +4.6	$-$7.7 / +9.0	$-$7.5 / +8.9
ISR/FSR	$\pm$4.5	$\pm$5.7	$\pm$4.8	$\pm$3.5
parton distribution function	$\pm$2.0	$\pm$2.1	$\pm$2.0	$\pm$2.1
parton shower	0.0 / +0.3	0.0 / +0.3	$-$0.3 / 0.0	$-$0.3 / 0.0
MC generator	$\pm$0.7	$\pm$0.7	$\pm$0.7	$\pm$0.7
τ identification (τ_1)	$\pm$5.0	$\pm$5.0	$-$3.0 / +3.2	$-$2.7 / +3.0
τ identification (τ_3)	$\pm$7.1	$\pm$7.1	$-$3.1 / +3.4	$-$2.9 / +3.2
total (τ_1)	$-$9.6 / +9.3	$-$10.6 / +10.1	$-$10.1 / +11.3	$-$9.7 / +11.1
total (τ_3)	$-$10.9 / +10.6	$-$11.7 / +11.3	$-$10.2 / +11.3	$-$9.8 / +11.2

Event yield

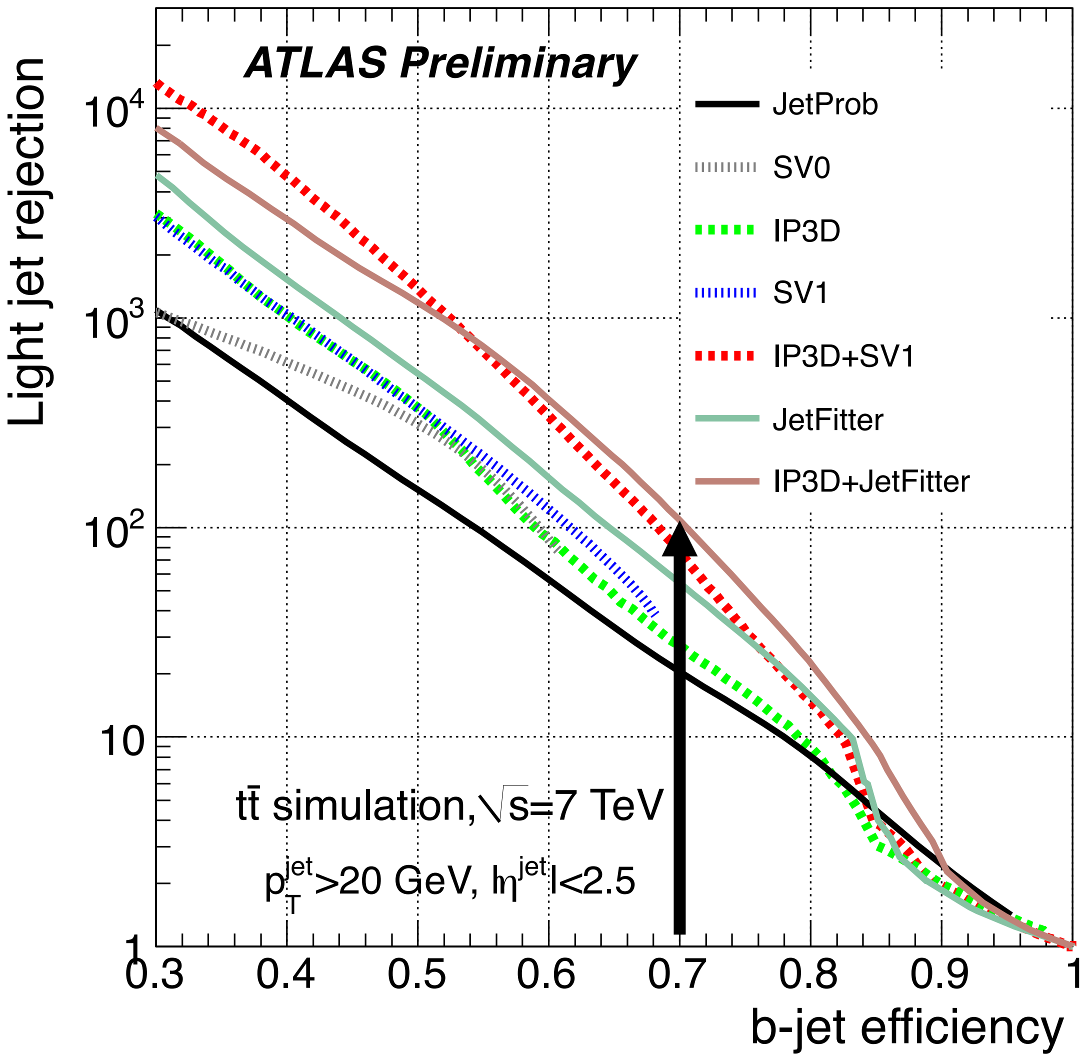
$\tau+\mu$	τ_1				τ_3			
	0 b-tags		≥ 1 b-tags		0 b-tags		≥ 1 b-tags	
	OS	SS	OS	SS	OS	SS	OS	SS
μ+jets	5005 ± 72	3022 ± 56	496 ± 17	297 ± 13	12230 ± 120	8669 ± 89	1293 ± 28	928 ± 24
multi−jets	465 ± 140	537 ± 160	117 ± 35	146 ± 44	995 ± 300	1123 ± 340	464 ± 139	401 ± 120
$t\bar{t}(\mu$+jets$)$	308 ± 4	163 ± 3	1528 ± 9	660 ± 6	685 ± 6	443 ± 5	3484 ± 13	2000 ± 10
$t\bar{t}(\mu+e)$	3 ± 1	< 1	12 ± 1	1 ± 1	1 ± 1	< 1	2 ± 1	< 1
$Wt(\tau+\mu)$	7 ± 1	< 1	18 ± 1	1 ± 1	2 ± 1	< 1	5 ± 1	< 1
$\mathrm{Z} \to \tau\tau$	301 ± 13	2 ± 1	16 ± 3	< 1	75 ± 7	1 ± 1	3 ± 2	< 1
$t\bar{t}(\tau+\mu)$	60 ± 2	< 1	390 ± 4	2 ± 1	17 ± 1	1 ± 1	118 ± 2	2 ± 1
Total	6149 ± 160	3724 ± 180	2577 ± 40	1106 ± 45	14010 ± 323	10240 ± 350	5371 ± 139	3322 ± 120
Data	5450 ± 74	3700 ± 61	2472 ± 50	1332 ± 36	13322 ± 115	10193 ± 101	5703 ± 76	3683 ± 61

$\tau+e$	τ_1				τ_3			
	0 b-tags		≥ 1 b-tags		0 b-tags		≥ 1 b-tags	
	OS	SS	OS	SS	OS	SS	OS	SS
e+jets	3949 ± 63	2590 ± 51	380 ± 20	256 ± 16	10140 ± 100	7530 ± 87	1120 ± 33	841 ± 29
multi−jets	602 ± 180	617 ± 185	165 ± 50	135 ± 41	2010 ± 600	2020 ± 600	690 ± 207	606 ± 182
$\mathrm{Z} \to ee$	92 ± 10	3 ± 2	9 ± 3	< 1	11 ± 3	2 ± 1	< 1	< 1
$t\bar{t}(e$+jets$)$	273 ± 17	146 ± 12	1335 ± 37	599 ± 24	633 ± 25	399 ± 20	3093 ± 56	1780 ± 42
$t\bar{t}(e+e)$	2 ± 1	< 1	11 ± 3	< 1	< 1	< 1	2 ± 1	< 1
$Wt(\tau+e)$	7 ± 3	< 1	17 ± 4	< 1	1 ± 1	< 1	6 ± 2	< 1
$\mathrm{Z} \to \tau\tau$	217 ± 15	2 ± 2	15 ± 4	< 1	56 ± 8	1 ± 1	3 ± 2	< 1
$t\bar{t}(\tau+e)$	54 ± 7	1 ± 1	342 ± 18	4 ± 2	15 ± 4	< 1	103 ± 10	2 ± 1
Total	5200 ± 190	3360 ± 190	2274 ± 68	995 ± 50	12870 ± 610	9950 ± 610	5020 ± 217	3226 ± 192
Data	5111 ± 71	3462 ± 59	2277 ± 48	1107 ± 33	12102 ± 110	9635 ± 98	5033 ± 71	3192 ± 56

CLs method


P(N)
Signal + background
Background only
CL$_b$
CL$_{s+b}$
N$_{observed}$
Number of events

b-tagging



Use IP3D + JetFitter
with 70% efficiency point

Light-flavor jet rejection
~ 100

Variables used for the BDT

Variable	Eqn.	Jet discriminants					
		Cut		LLH		BDT	
		1	m	1	m	1	m
R_{track}	11	●	●	●	●	●	●
f_{track}	12	●	●			●	●
f_{core}	13			●	●	●	●
$N^{\text{iso}}_{\text{track}}$		●	●	●		●	●
R_{Cal}	14			●		●	●
f_{iso}	15						
$m_{\text{eff. clusters}}$	16					●	●
m_{tracks}	18				●		●
$S_{\text{T}}^{\text{flight}}$	19		●		●		●
$S_{\text{lead track}}$	20					●	●

- p_T weighted track width

$$R_{\text{track}} = \frac{\sum_i^{\Delta R_i<0.4} p_{T,i}\Delta R_i}{\sum_i^{\Delta R_i<0.4} p_{T,i}}$$

- E_T weighted shower width

$$R_{\text{cal}} = \frac{\sum_i^{\Delta R_i<0.4} E_{T,i}\Delta R_i}{\sum_i^{\Delta R_i<0.4} E_{T,i}}$$

- Effective invariant mass

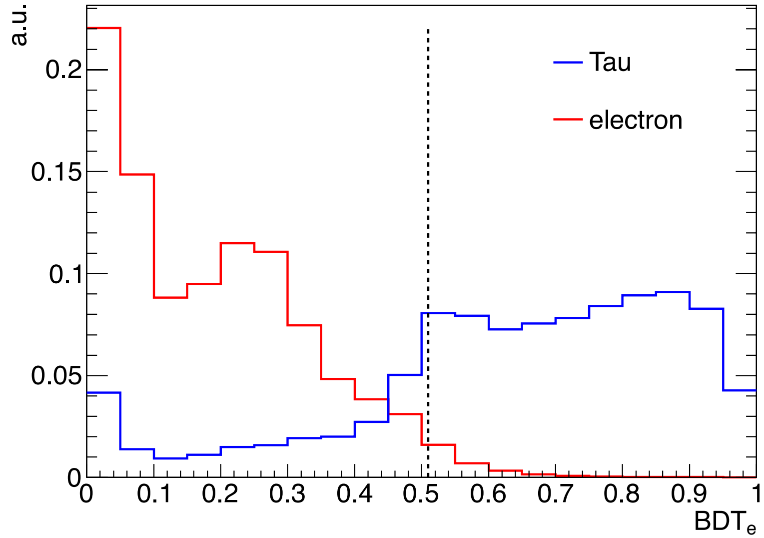
$$m_{\text{eff. clusters}} = \sqrt{\left(\sum_{\text{clusters}} E\right)^2 - \left(\sum_{\text{clusters}} \vec{p}\right)^2}$$

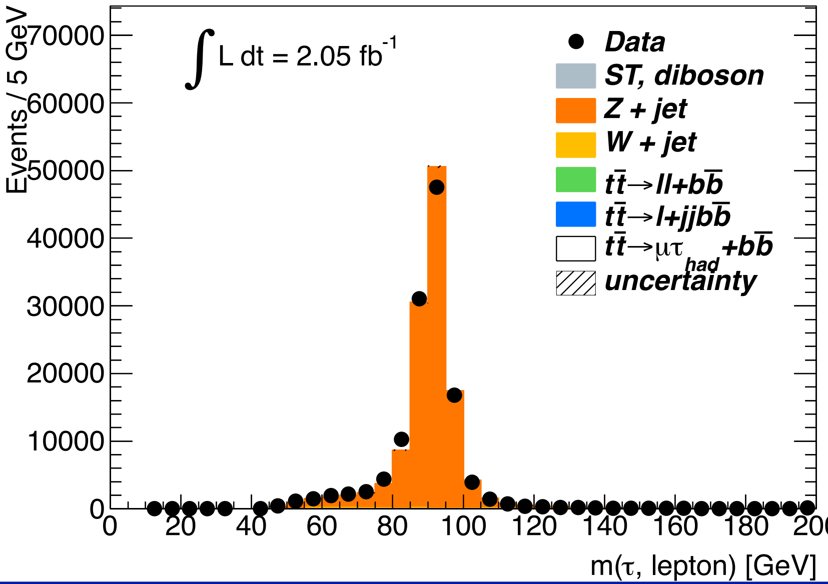
- Centrality fraction

$$f_{\text{core}} = \frac{\sum_i^{\Delta R_i<0.1} E_{T,i}}{\sum_j^{\Delta R_j<0.4} E_{T,j}}$$

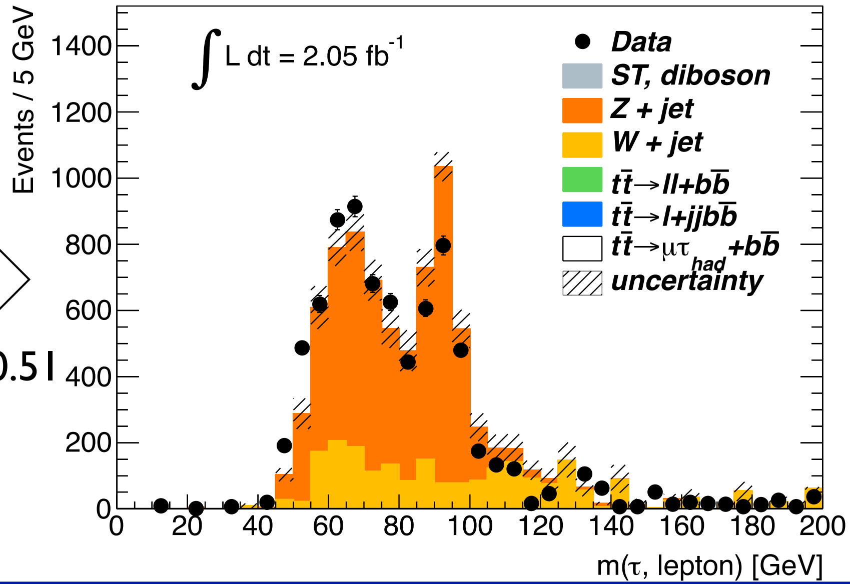
Boosted Decision Tree for electron

- Boosted Decision Tree against electron is also developed
- Cut on BDTe > 0.51 to remove fake electrons
- Rejection factor ~ 60, estimated b
$Z \rightarrow ee$ control region



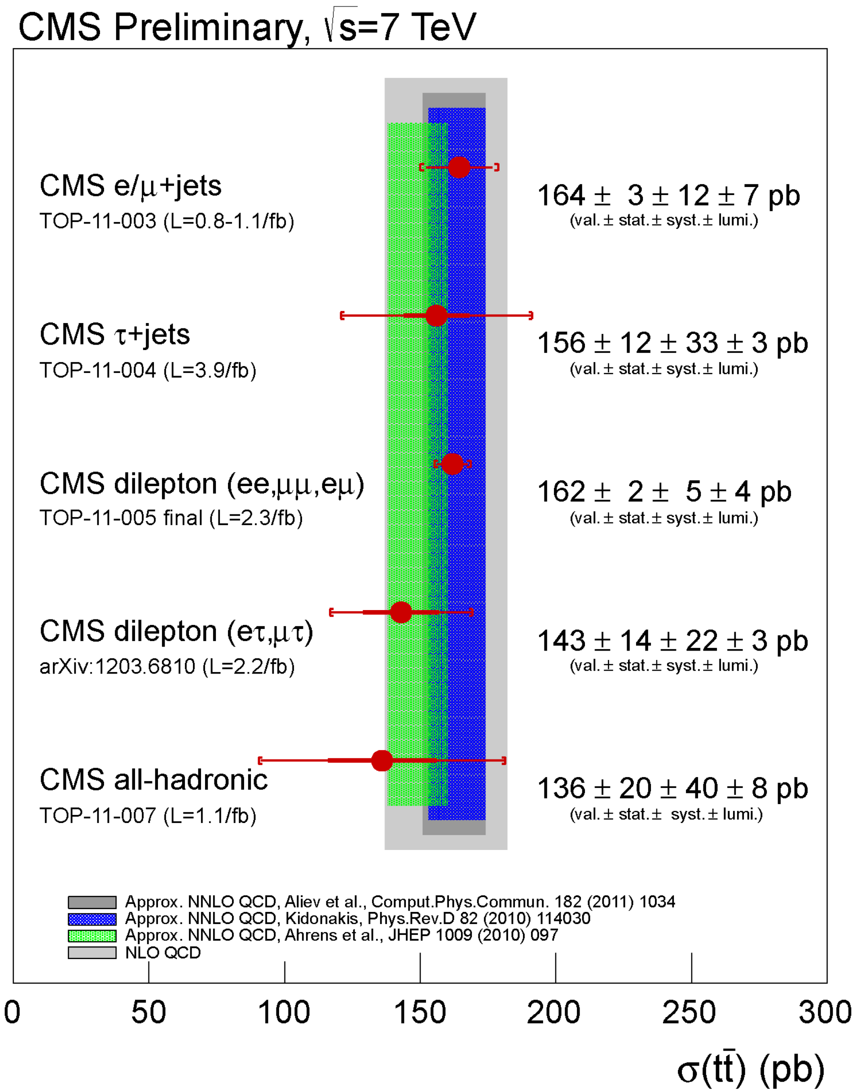


BDTe > 0.51



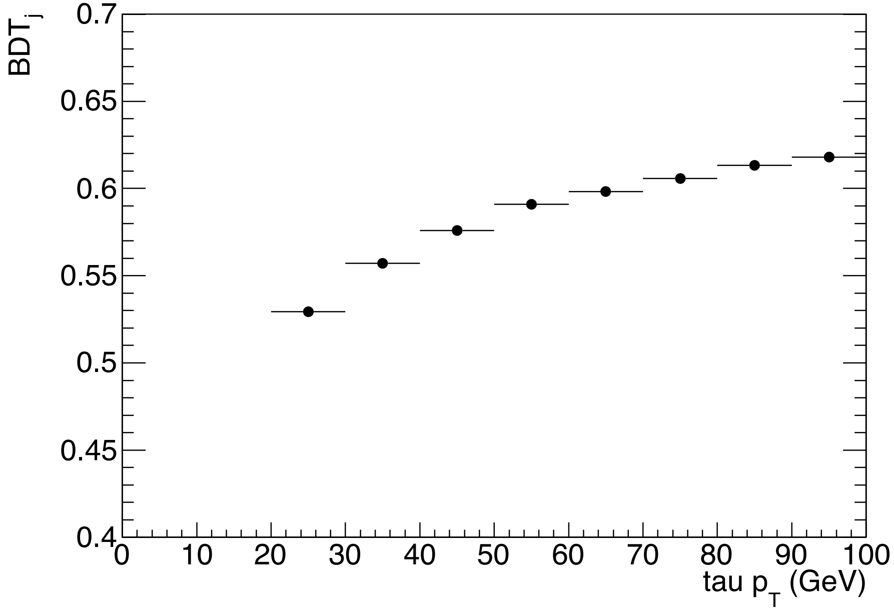
Comparison with CMS

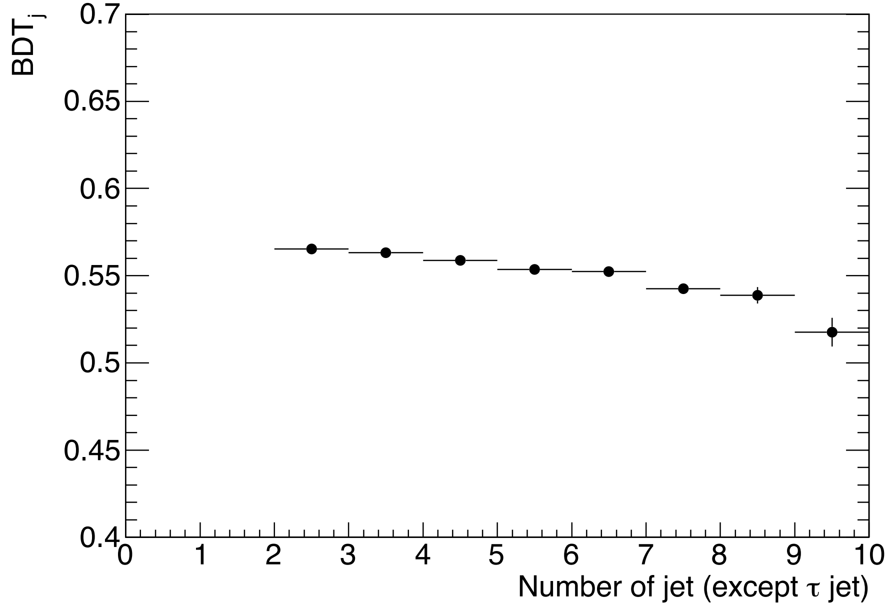
$t\bar{t}$ channel	ATLAS	CMS
$\ell + \ell$	10% (0.7)	9% (1.1)
ℓ + jet	7% (0.7)	9% (1.1)
$\tau + \ell$	13% (2.1)	18% (2.2)
τ + jet	24% (1.7)	23% (3.9)
all hadronic	32% (4.7)	33% (1.1)
combination	6%	8%



BDT dependence on Kinematics

- Higher p_T result in higher BDT
- Higher Number of jet result in lower BDT

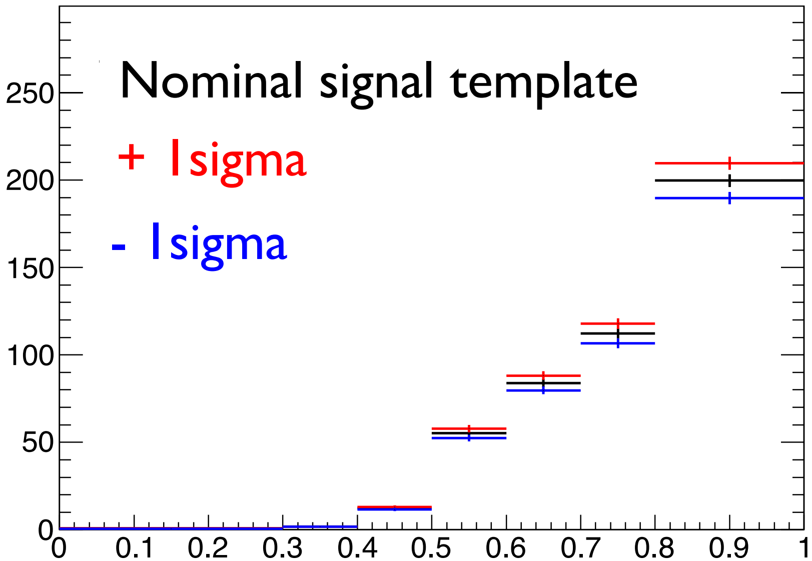


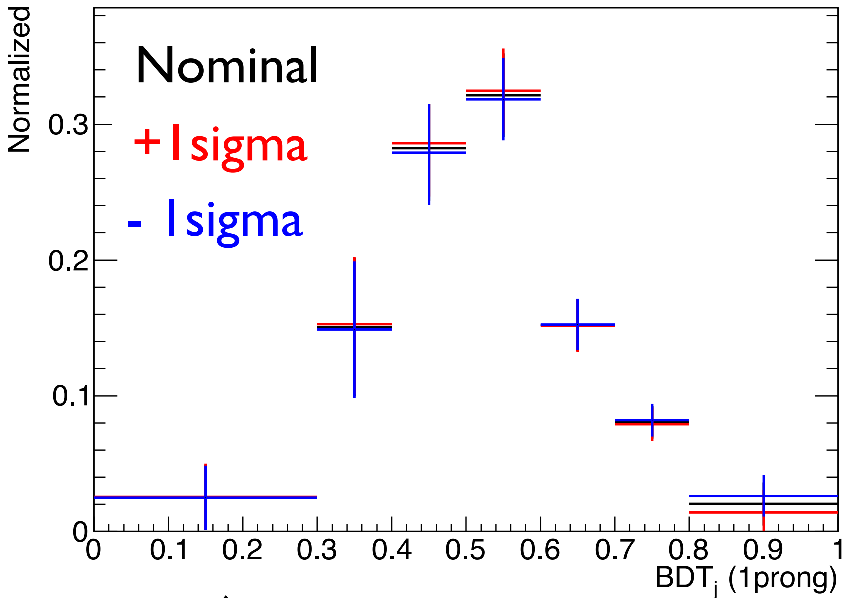


- tt has higher p_T & higher jet multiplicity
- W + jet has lower p_T & lower jet multiplicity (0 bjet)

Tau ID systematic uncertainty

- If there are more tau than nominal MC,
  - Signal template shape stay same (no effect)
  - Subtraction of $Z \to \tau\tau$, tt in 0 b-jet region goes up
  - As a result, BG template is distorted

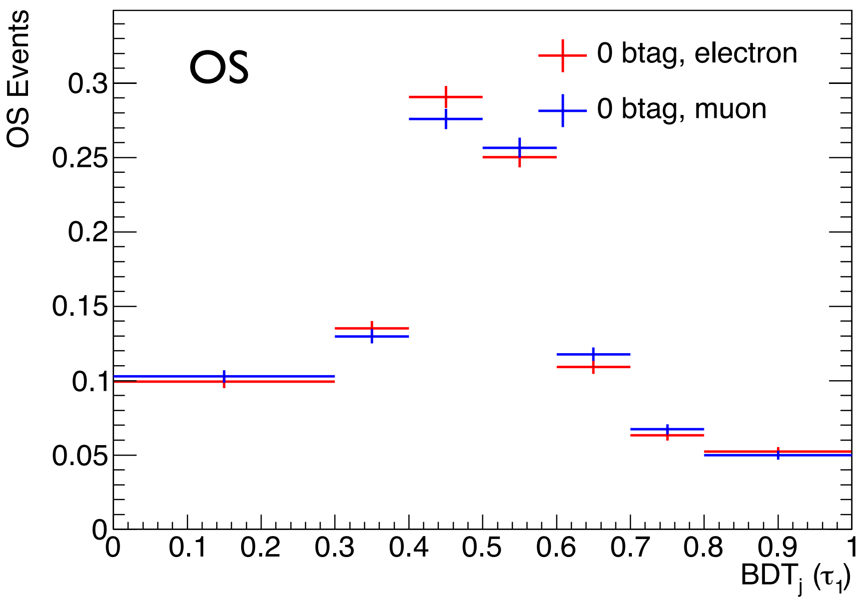


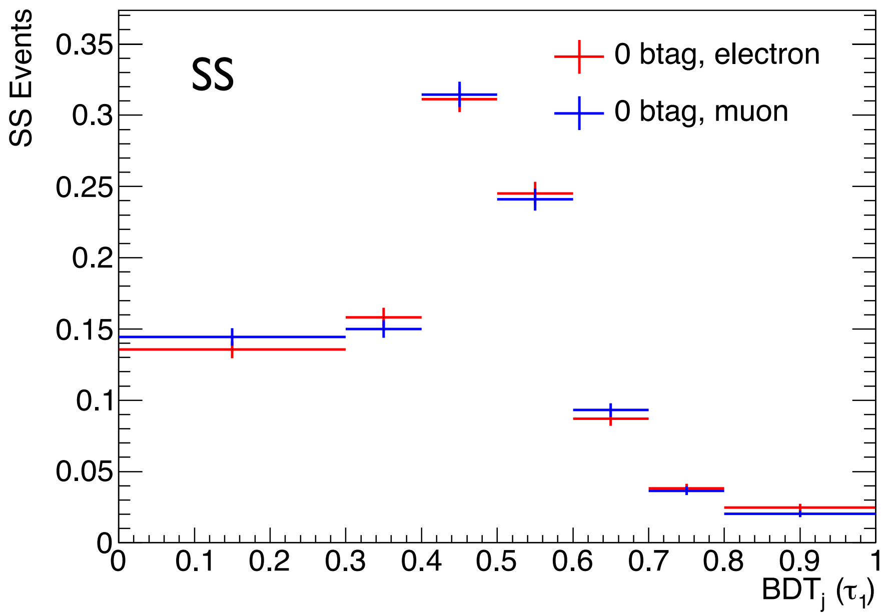


- Shift in acceptance(↑) and N_{signal} (↑) are cancelled out
- The opposite thing occurs in case of *b*-tagging efficiency

Combination of the BG template

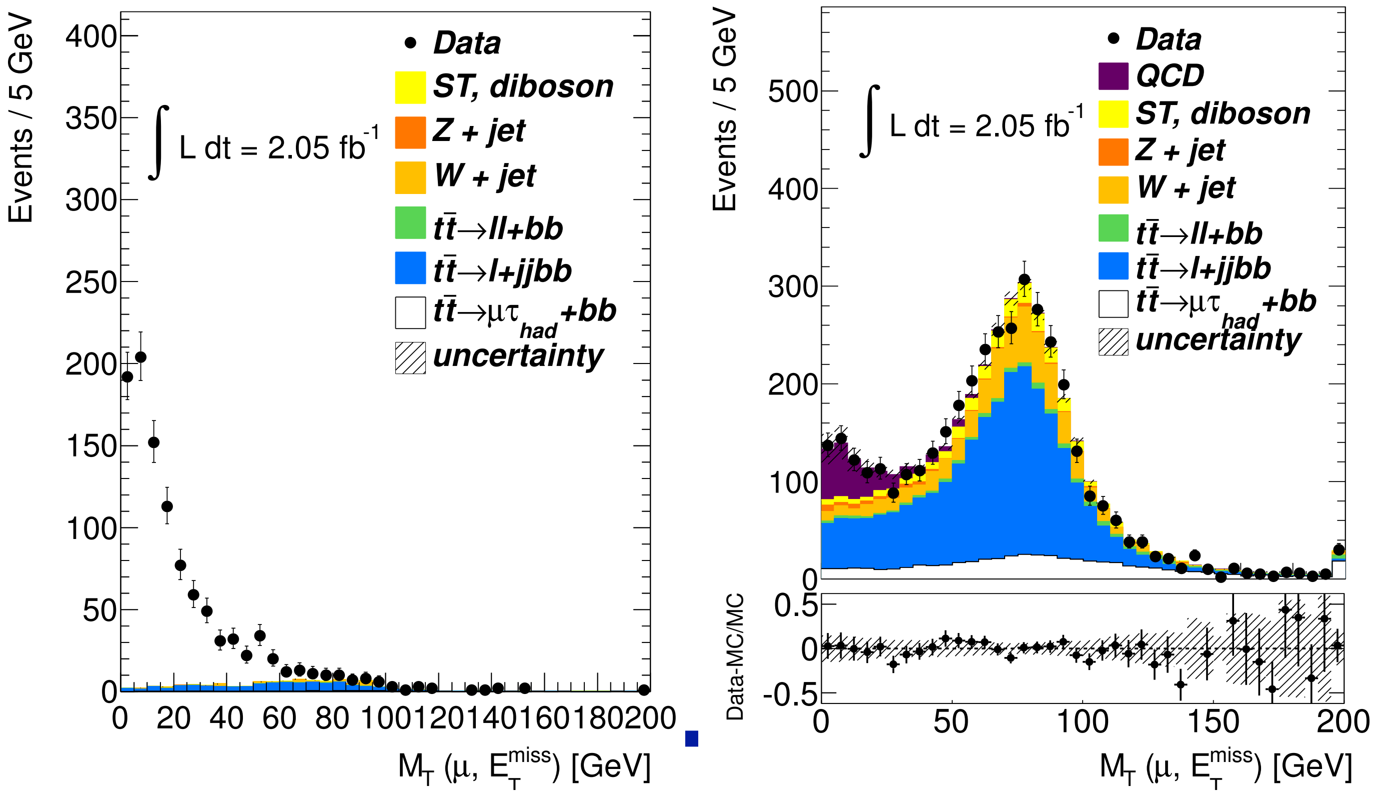
- electron & muon channel are combined when constructing the background template
  - After subtracting tau and electron component, background BDT distribution are compared and found to be identical





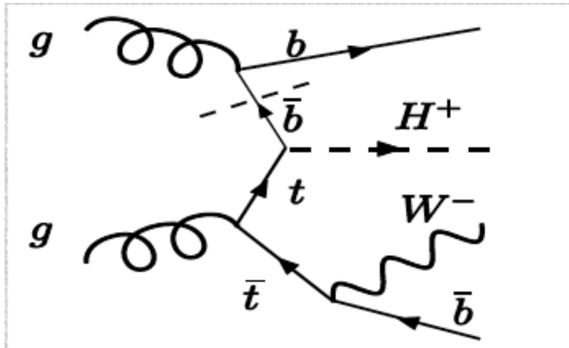
QCD multi-jet estimation

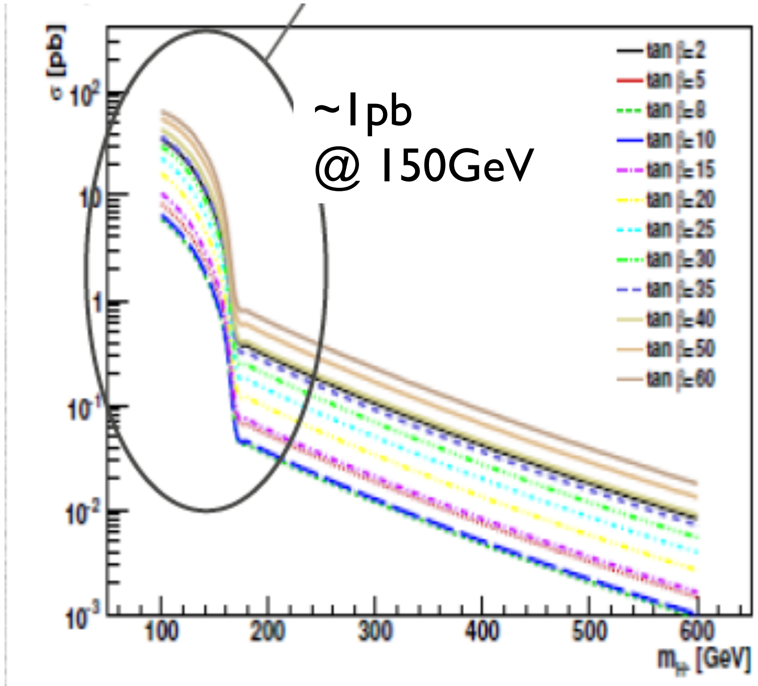
- Template of the QCD distribution is derived from non-isolated lepton sample
- The normalization is derived by using M_T < 40 GeV by fitting QCD template and other SM processes

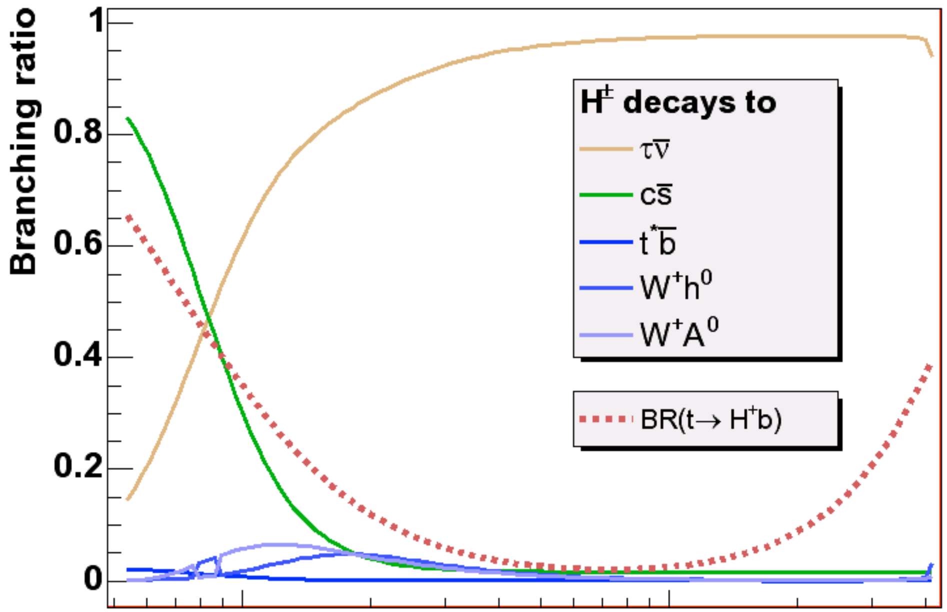


Production process at LHC

- Light charged Higgs ($m_{H\pm} < m_{t\text{-quark}}$)
  - gluon fusion + tt production
- Heavy charged Higgs ($m_{t\text{-quark}} < m_{H\pm}$)
  - gb fusion





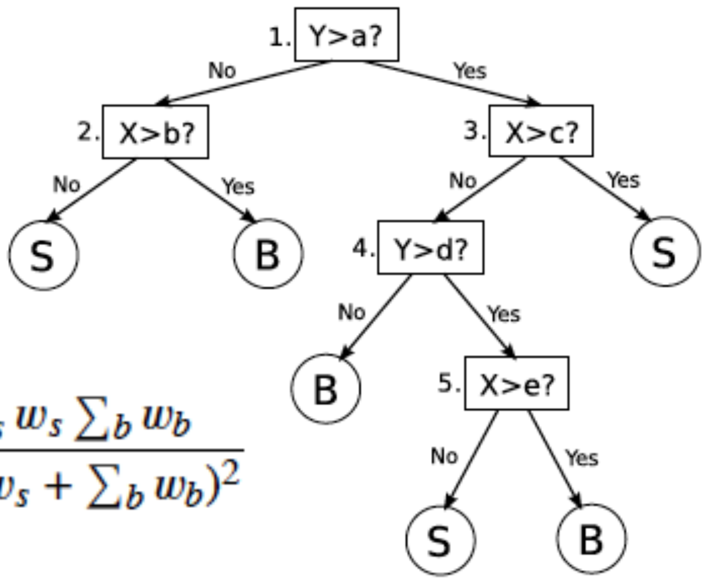


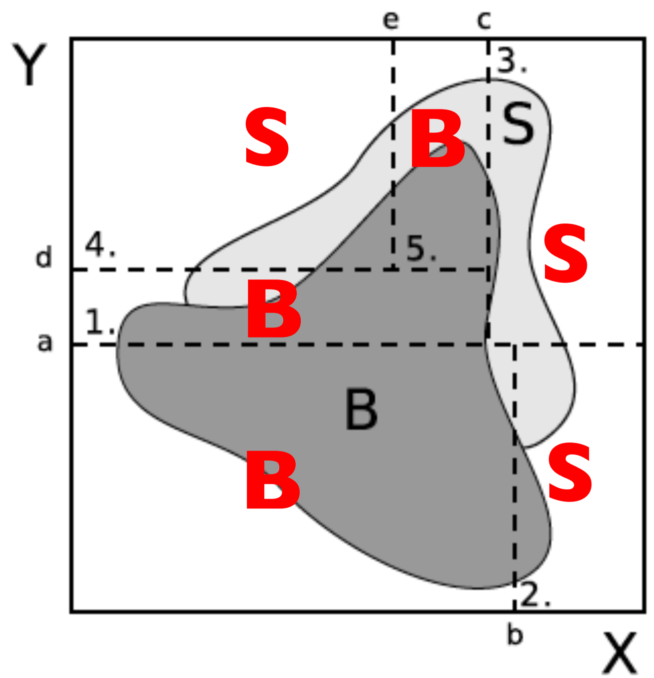
Boosted Decision Tree

- Multivariable, trained by known S/B sample
  - Consists of lots Yes / No questions

$$p = \frac{\sum_s w_s}{\sum_s w_s + \sum_b w_b}$$

$$i_{Gini} = p(1-p) = \frac{\sum_s w_s \sum_b w_b}{(\sum_s w_s + \sum_b w_b)^2}$$





  - Cut is optimized at each question so that signal purity (p) times BG purity (1-p) become minimum
  - The output value is a purity

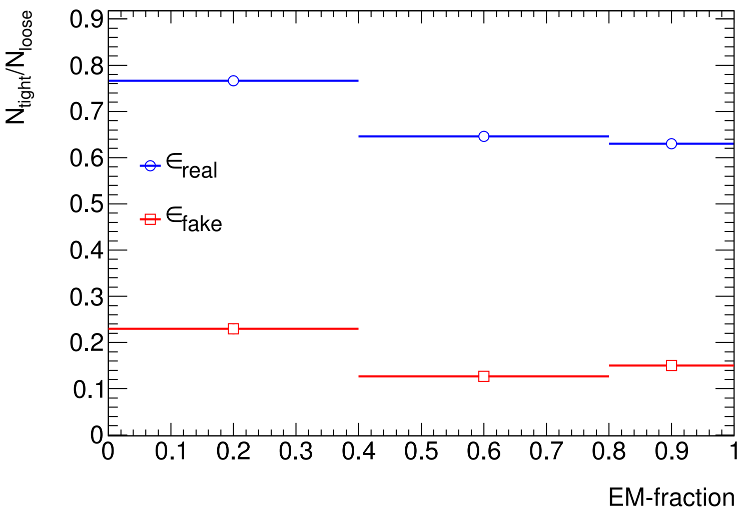
Matrix Method

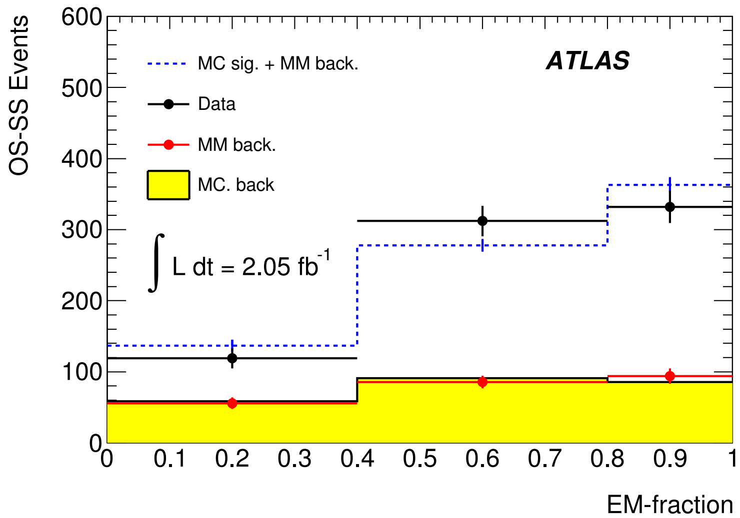
- Alternative background estimation method
- Solve simple system of equation for BDT = 0.7

$$\varepsilon_{\text{real}} = \frac{N_{\text{real}}^{\text{tight}}}{N_{\text{real}}^{\text{loose}}}, \qquad \varepsilon_{\text{fake}} = \frac{N_{\text{fake}}^{\text{tight}}}{N_{\text{fake}}^{\text{loose}}}$$

efficiency from MC
fake rate from Data

$$N_{\text{real}}^{\text{tight}} = N_{\text{data}}^{\text{tight}} - \frac{\varepsilon_{\text{fake}}}{\varepsilon_{\text{real}} - \varepsilon_{\text{fake}}} \left(N_{\text{data}}^{\text{loose}} \varepsilon_{\text{real}} - N_{\text{data}}^{\text{tight}} \right)$$



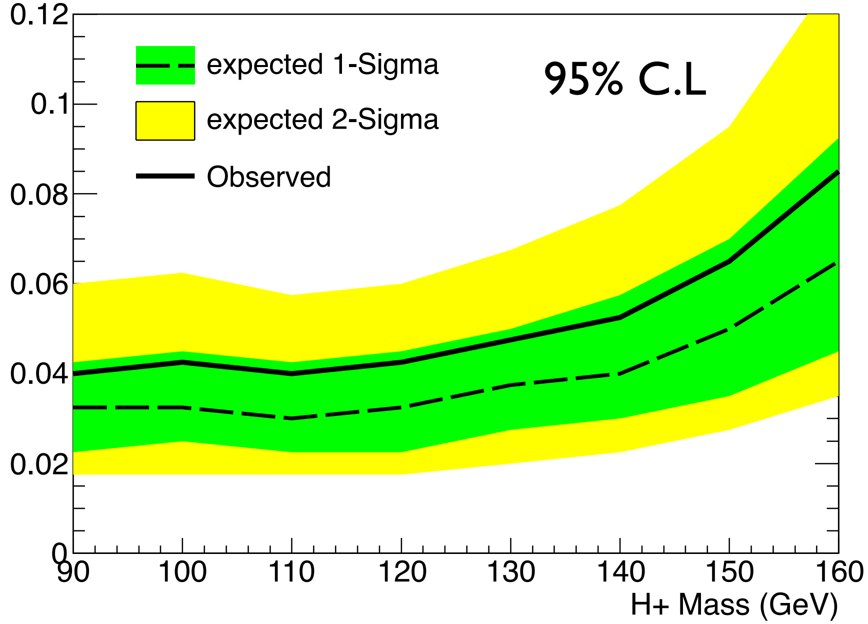


165
± 13 (stat)
+16/-15 (syst)
± 6 (lum)

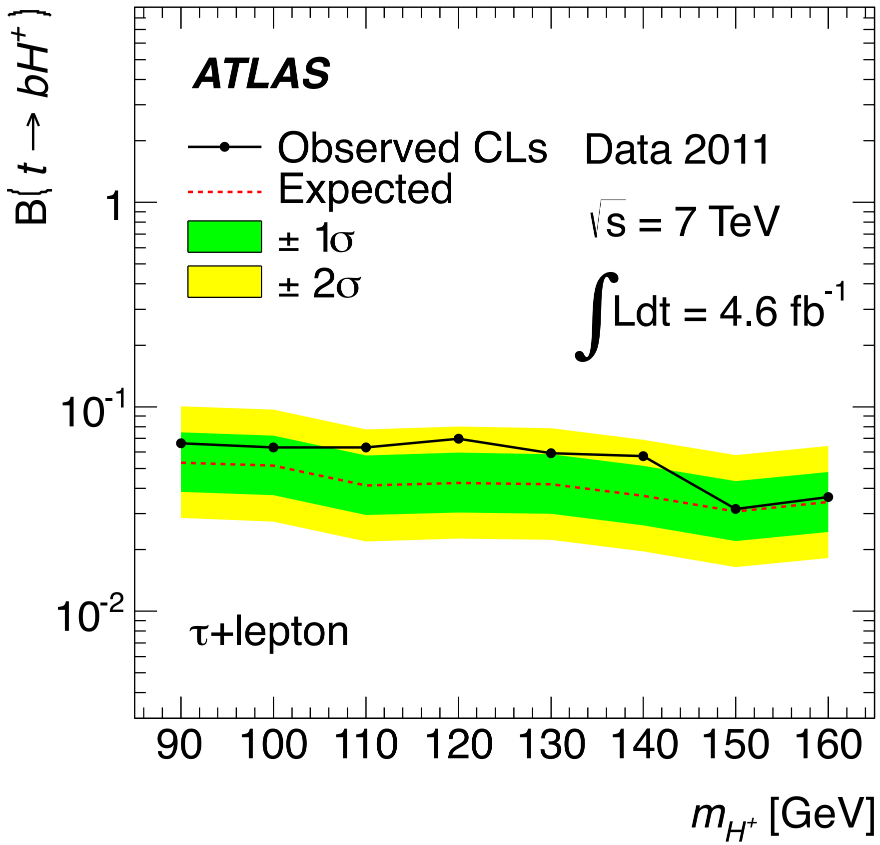
Interpretation to H±

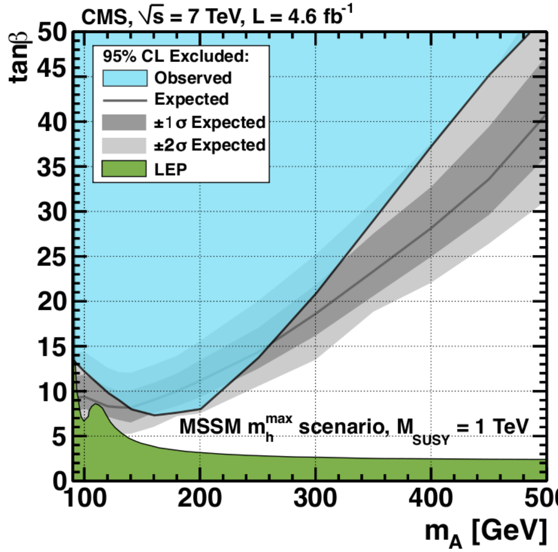
Our result

$B(t \to H^{\pm}b)$, assuming $B(H^{\pm} \to \tau\nu) = 1$

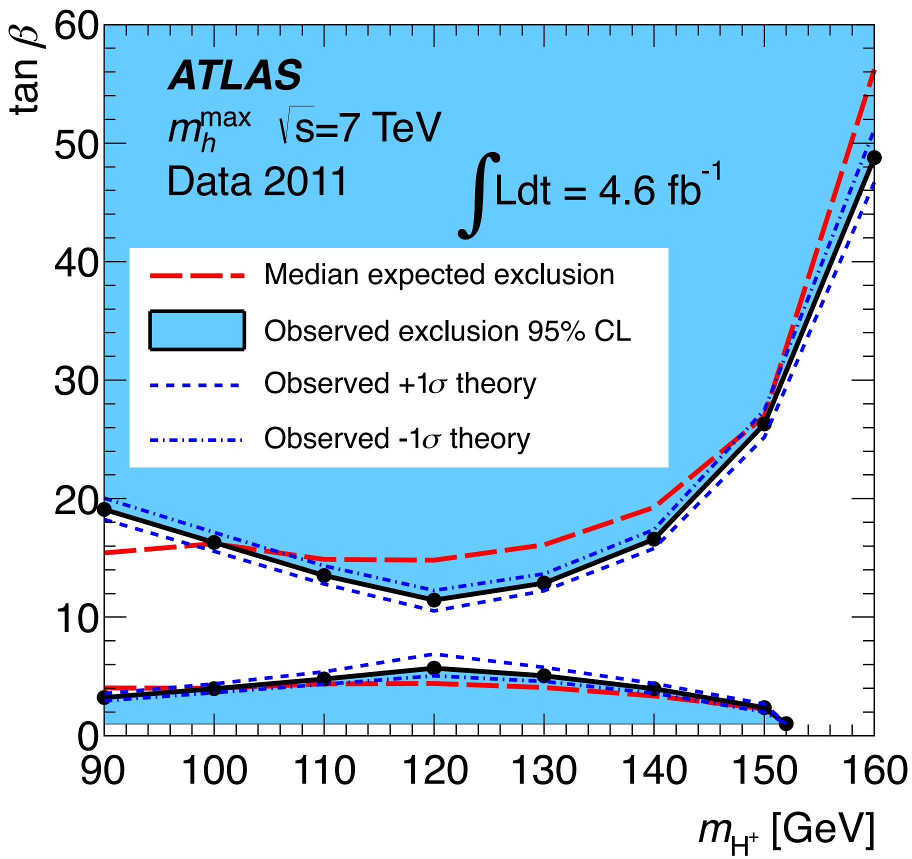


charged Higgs search @ ATLAS

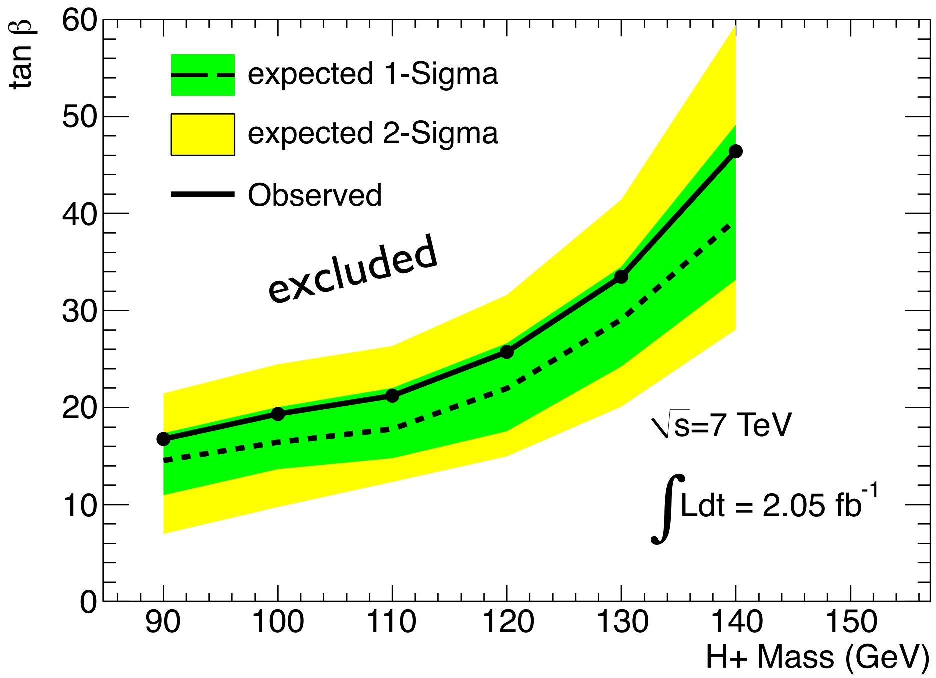




Charged Higgs boson search @ ATLAS



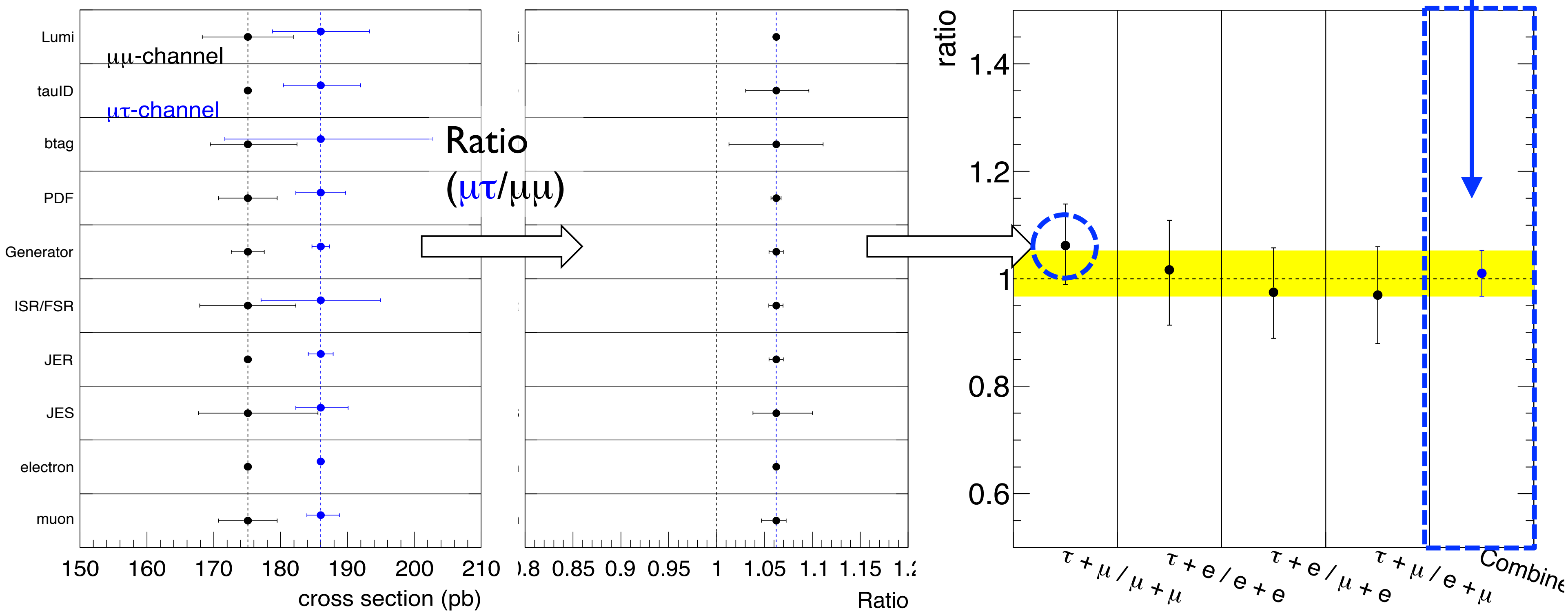
Allowed region in tanβ - $m_{H\pm}$ plane



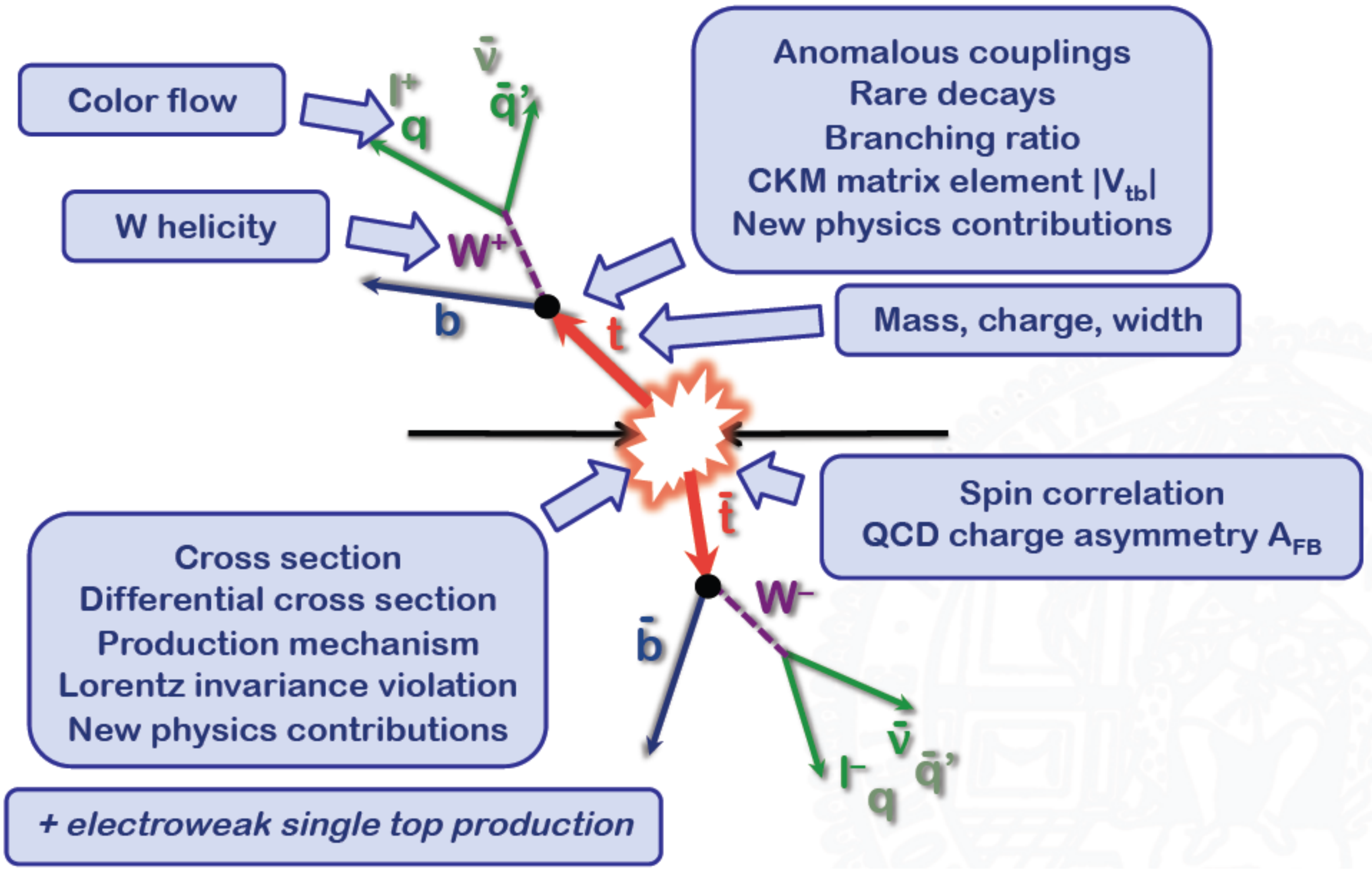
Ratio Measurement

- Ratio of the observed cross-section between di-lepton and the τ + lepton channel
  - Cancel out common systematic uncertainty
  - Enhancement from unity indicates new physics

Combined
1.01 ± 0.04

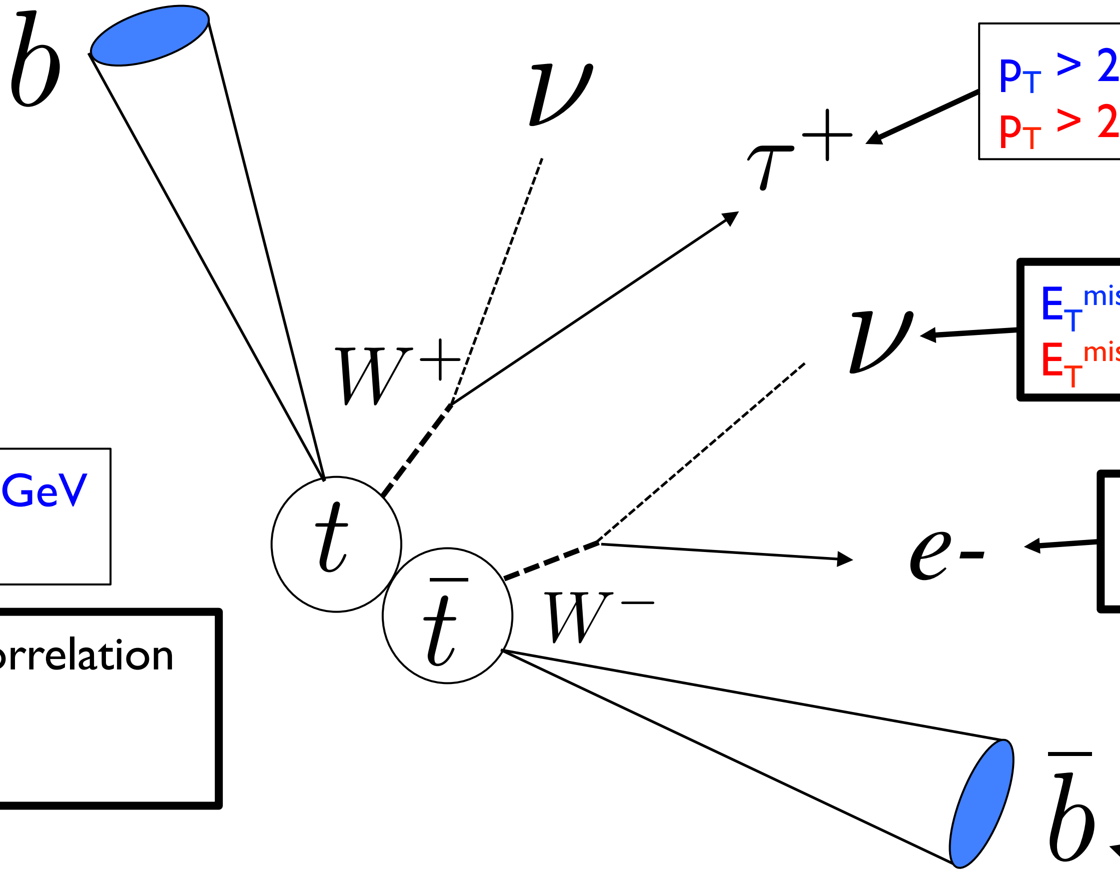


What is interesting about *t*-quark ?



Difference of the Event selection

ATLAS
CMS



p_T > 20 GeV
p_T > 20 GeV

E_T^{miss} > 30 GeV
E_T^{miss} > 45 GeV

H_T > 200 GeV
---

p_T > 22 GeV
p_T > 35 GeV

Charge correlation
OS – SS
OS

2 jets with
p_T > 25 GeV
p_T > 35 GeV

≥ 1btag jet with
70% eff. point
76% eff. point

Acceptance (Br inc.) : ATLAS = 0.1%, CMS = 0.03%
S/N : ATLAS = 0.1, CMS = 0.5
Large stat. in ATLAS, while better S/N in CMS

Comparison of Systematic uncertainty

electron channel	ATLAS	CMS
Tau identification	3%	6%
Tau miss-identification modeling	5% Modeled by anti b-tag data	12.6%
b-tag	8%	5%
Jet	3%	5%
PDF, generator, ISR/FSR	4%	4%
electron	3%	3%

- Difference of τ identification, Jet, b-tag is understandable
  - Due to the template fitting (correlation between $\mathcal{A}$, BG template)
  - As far as comparing with dA/A, it is same order
- Difference arises from τ miss-identification modeling

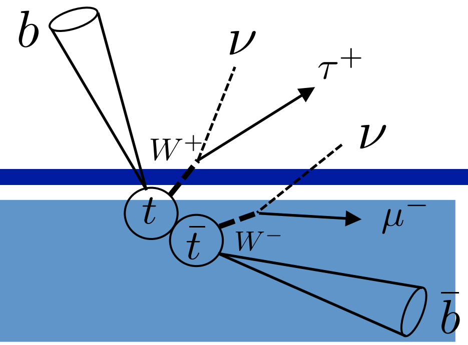
Tau miss-identification modeling

- So-called, background estimation uncertainty
- ATLAS
  - Background is modeled by anti b-tag CR
  - Kinematically close to the signal sample, enough not to add additional uncertainty
  - OS – SS subtraction eliminate the uncertainty related to the jet composition (b-jet, gluon jet)
- CMS
  - Miss-identification rate is estimated by W+1jet control region and QCD multi-jet control region, like,

$$N^{\mathrm{misid}} = \frac{\sum_i^N \sum_j^n w^j_{\mathrm{W+jets},\,i} + \sum_i^N \sum_j^n w^j_{\mathrm{QCD},\,i}}{2}$$

$$\Delta N^{\mathrm{misid}} = \frac{\sum_i^N \sum_j^n w^j_{\mathrm{W+jets},\,i} - \sum_i^N \sum_j^n w^j_{\mathrm{QCD},\,i}}{2}$$

Event selection



Muon channel	σ_{tt} measurement	$H^{\pm}$ search
Trigger	Single lepton trigger, p_T > 18 GeV	
Lepton	p_T > 20 GeV	
Tau	OS tau candidate p_T > 20 GeV	OS tau (**likelihood ID**, 30% eff.) p_T > 20 GeV
Jets	≥ 2 jets (p_T > 25 GeV)	≥ 2 jets (p_T > 20 GeV) |JVF| > 0.75
b-jet	≥ 1 b-tagged jet (70% eff point)	
Missing E_T	E_T^{miss} > 30 GeV	--- (use as final discriminant)
ΣE_T	ΣE_T > 200 GeV	Σp_T > 100 GeV (All track associated to the PV)

- σ(tt) analysis uses BDT as a final discriminant, while $H^{\pm}$ analysis uses E_T^{miss}
- Acceptance (Br. included) → σ(tt) : 0.1%, H : 0.08%